LANDSAT CLASSIFICATION: EVALUATION OF IMAGE ANALYSIS METHODOLOGIES FOR WILDLIFE HABITAT MANAGEMENT AND RESEARCH PLANNING

Final Report

INTEGRATED WILDLIFE INTENSIVE FORESTRY RESEARCH

Province of British Columbia

A cooperative project between the Ministries of Environment and Forests

LANDSAT CLASSIFICATION: EVALUATION OF IMAGE ANALYSIS METHODOLOGIES FOR WILDLIFE HABITAT MANAGEMENT AND RESEARCH PLANNING

Final Report

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FOREWORD

This publication reports the results of the IWIFR project Landsat Image Classification as a Wildlife Habitat Classification System. The initial recommendation for this project is presented in the problem analysis *Landsat Classification for Wildlife Habitat Management and Research Planning* (Sadoway 1980a). The terms of reference are outlined in the working plan *Landsat Classification: Evaluation of Image Analysis Methodologies for Wildlife Habitat Management and Research Planning* (Sadoway 1980b). Subsequent changes to the working plan terms of reference are presented in Appendix G.

The objective of the working plan was (1) to evaluate three Landsat image classification methodologies: paper print, positive transparency, and digital computer tapes; and (2) to evaluate the classification system developed (Sadoway 1980b).

The Project was undertaken in two stages:

The first stage involved the development of the wildlife habitat classification maps using three Landsat image classification methodologies. The reports on these 3 methods are presented in Appendices A, B, and C.

The second stage involved the evaluation and comparison of the three mapping methods. This report presents the results of the comparative evaluation.

report

Evaluation of Three Methods of WILDLIFE HABITAT MAPPING Using Landsat Imagery

for B.C. MINISTRY OF FORESTS, RESEARCH BRANCH
B.C. MINISTRY OF ENVIRONMENT, FISH AND WILDLIFE BRANCH

Project No. 81-068
February 1983

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In particular, we thank Rick Ellis, Program Manager, Wildlife Habitat Research, Research Branch, Ministry of Forests, Victoria, for his advice and involvement in all phases of this work.

The original problem analysis and working plan for the study were prepared by Karen Sadoway of the Research Branch. Her assistance, advice, and attention to detail throughout the study is gratefully acknowledged.

The three Landsat image analysts Messrs. Kent Watson, John Bunning and Dr. Geoff Tomlins all provided information vital to this evaluation. We thank them for their cooperation and high quality work.

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Wayne Biggs
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SUMMARY

The accuracy, utility and cost-effectiveness of three methods of mapping the wildlife habitats of a portion of northern Vancouver Island from Landsat imagery were evaluated and compared.

The methods were:

* Colour Additive Viewer (CAV) analysis: modified CAV map.

* Visual analysis of Landsat paper prints: Visual map

* Digital analysis of DICS tapes: Thematic map

The following factors made objective and rigorous comparisons of the three methods difficult:

* standard habitat types were not defined for all three methods.

* Contrary to what was proposed in the Terms of Reference (Sadoway, 1980b) the CAV analysis was performed using different LANDSAT imagery (1980) and visual analysis of

cibachrome paper prints, rather than by mapping directly from the CAV screen. This departure from the standard method of CAV mapping produced a modified CAV map.

* the modified CAV map was produced at a scale different from the other two maps.

* different study area boundaries were used for the Thematic map than for the other two.

Despite these complications, several conclusions are clear. The modified CAV method and the visual analysis of paper prints were similar with respect to the wildlife habitat types which could be mapped and in the type boundary locations. Both maps were similar in accuracy although the modified CAV map was slightly more accurate than the visual map. The Thematic map was the least accurate of the three. Overall accuracy was estimated to be 89% for the modified CAV map, 81% for the visual map and 61% for the thematic map. Ninety-five percent confidence intervals for accuracy were:

* Modified CAV - 84% to 94%

* Visual - 75% to 87%

* Thematic - 33% to 89%.

These results are compatible with the predicted accuracy for the CAV and visual analysts (Watson and Bunning) in their reports (see Appendix A and B).

SUMMARY

The visual map produced by paper print analysis was the least expensive method of the three. The modified CAV map was approximately twice as expensive as the paper print analysis and the digital analysis was about 4 1/2 times as much as the paper print analysis and 2 times more than the modified CAV method.

The wildlife biologists and foresters surveyed preferred the visual map and the modified CAV map over the Thematic map. The user survey data reveals a slight preference for the visual map over the modified CAV map; however, these two mapping methods were generally rated so closely that they were considered more or less equivalent.

The classification system of the digital analysis was very broad compared to the other two methods. The modified CAV was considered superior by some reviewers because finer age classes of immature forests were identified.

In summary, the visual analysis of Landsat paper prints, and the modified CAV method were clearly superior to the digital analysis of DICS tapes for the production of wildlife habitat maps using accuracy, cost and utility as criteria. However, it was recognized that the technology of digital analysis is rapidly changing and this mapping method could have several applications for habitat monitoring studies determining the spatial distribution of habitat types for a large area and mapping areas with low habitat diversity.

1
INTRODUCTION

This study arose in response to a request by the IWIFR, Technical Working Group to ccmpare and evaluate wildlife habitat maps prepared by the three standard techniques of mapping from Landsat imagery. Talisman Land Resource Consultants were contracted to provide these services in July 1981.

Talisman personnel responsible for the comparative analysis, project management and report preparation were Wayne Biggs, P.Ag., habitat biologist, Victoria, and Jace Standish R.P.F., Vancouver.

The initial recommendation for this project is presented in the problem analysis Landsat Classification for Wildlife Habitat Management and Research Planning (Sadoway, 1980a). The general terms of reference for each of the three Landsat image analysts and for the comparative evaluation are outlined in the working plan Landsat Classification: Evaluation of Image Analysis Methodologies for Wildlife Habitat Management and Research Planning (Sadoway, 1980b). Subsequent changes to the working plan terms of reference are presented in Appendix G.

INTRODUCTION

The primary objective of this study was to evaluate and compare three techniques of classifying and mapping of wildlife habitats from Landsat imagery. The three techniques evaluated were:

(1) The Colour Additive Viewer (CAV) analysis of Landsat positive transparencies. Analyst: E. Kent Watson, M.Sc., International Range Remote Sensing Ltd., Kamloops, B.C.

(2) The visual analysis of Landsat paper prints (Visual). Analyst: John Bunning, C.E.T. Talisman Land Resource Consultants, Vancouver, B.C.

(3) The digital analysis of DICS computer tapes of Landsat data (Thematic) Analyst: Geoff Tomlins Ph.D., B.C. Research, Vancouver, B.C.

The study area is coverd by a 2 X 2 NTS quadrant block (92K 4,5 and 92L 1,8) partly within the Sayward Forest, on northern Vancouver Island (Figure 1). This area was selected because it is currently the focus of three studies: a Roosevelt elk study (EP. 915), a black-tail deer study (EP. 923), a MOF Vancouver Region ecosystem study, and it has a forest mosaic of currently logged, recently logged 30 year old second growth, and mature forest (Sadoway 1980a).

Each Landsat analyst was provided with all materials necessary to produce a wildlife habitat map of the study area. A report describing methods of map production, cost, time, materials, predicted accuracy and precision was prepared by each analyst as part of the assessment. A brief account of the general methods used by the three analysts is presented in Chapter 2.

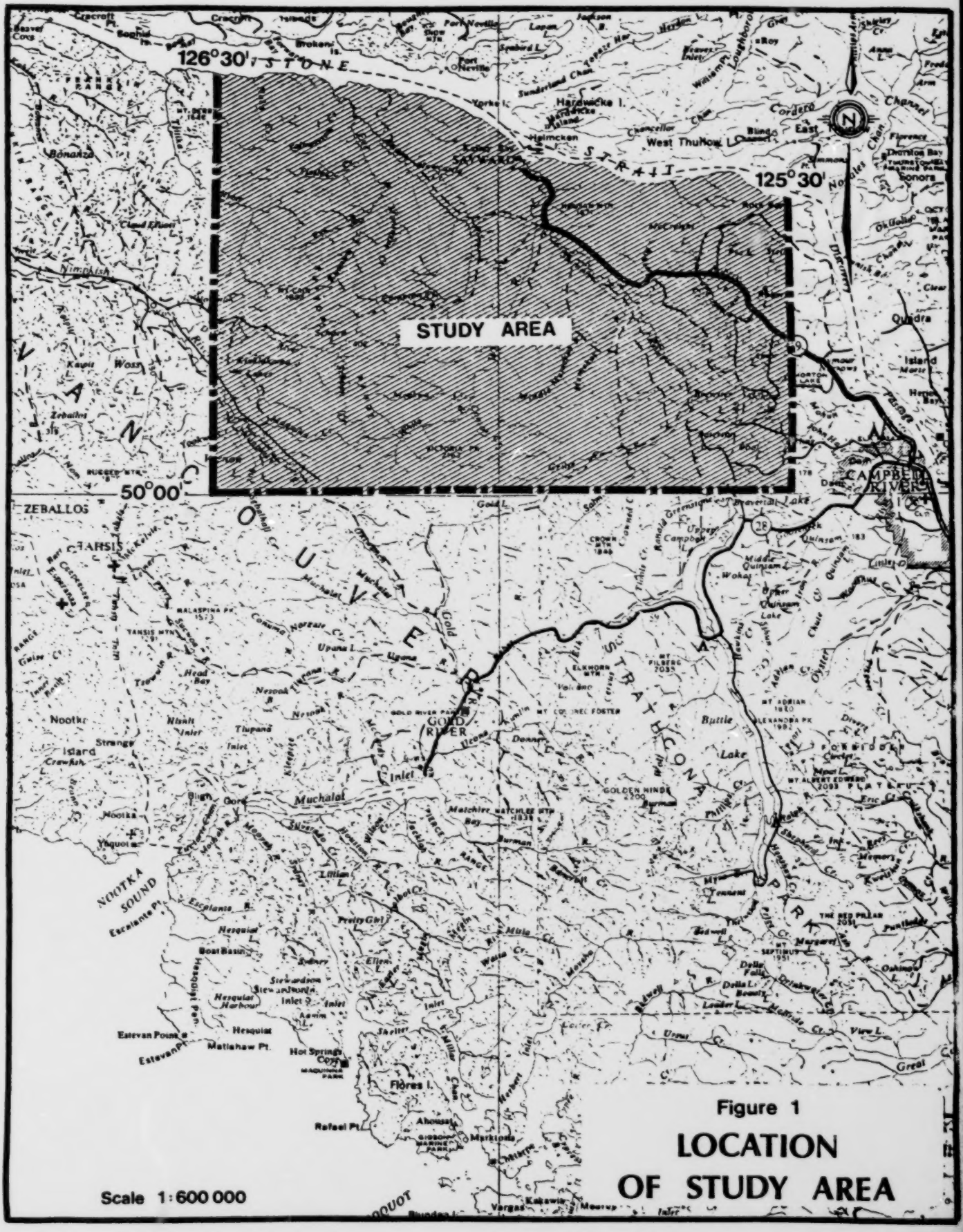

Figure 1

LOCATION OF STUDY AREA

Specific details on each method are presented in the analyst' report (Appendix A, B and C).

Chapter 3 is a description of the methods used to analyse and evaluate the three wildlife habitat maps.

The results of this comparitive analysis are presented in Chapter 4.

The findings of this evaluation and a discussion on the use of Landsat imagery for wildlife habitat map production and other ecological studies is presented in Chapters 5 and 6.

2

DESCRIPTION OF WILDLIFE HABITAT MAPPING TECHNIQUES

General terms of reference for the production of the maps were presented in the Working Plan (Sadoway, 1980b) and details regarding map production were developed following discussions between the project coordinator, Karen Sadoway, and each of the analysts. The three analysts were selected and map production was done under contract to the IWIFR Program.

Each analyst was required to develop a classification scheme and an appropriate wildlife habitat map legend. As each of the analysts was familiar with the production of habitat maps using their particular mapping techniques, it was assumed that all classification systems were the best and the most detailed each method would allow. The wildlife habitat map legend for the CAV, Visual and Thematic maps are presented in Figures 2, 3, and 4.

A brief description of the techniques employed by three analysts is presented below.

FIGURE 2

LEGEND FOR THE COLOUR ADDITIVE VIEW
MAP: K. WATSON, ANALYST

LEGEND

MAPPING CLASSIFICATION		CRITERIA AND REMARKS
I	Old Growth (Coniferous)	- Separated by dark brownish-red hue.
	1. Over Mature	- Oldest forest stands present. Darkest land hue on the image.
	2. Mature	- Stands younger aged than Over Mature class.
II	Second Growth (Coniferous)	- Lighter shade of brownish red when compared to Mature types.
	3. Old Second Growth	- Younger stands than Mature types. These stands associated with old clearcuts or burned over areas.
	4. Recent Second Growth	- Younger coniferous vegetation than Old Second Growth class found on more recent cutovers and burned areas.
III	Second Growth (Deciduous)	- Separated by bright red hue.
	5. Old Second Growth	- Deciduous cover within this class includes mature deciduous stands found on deciduous producing sites. This class is associated with old clearcuts or burned over areas.
IV	Recent Logging	- Bare ground exposed, but contains variations of light red hues interspersed with whitish tones of bare ground. Vegetation may be composed of forbs, deciduous or young conifer species.
	6. Canopy Cover 60-100%	- Deciduous vegetation dominant vegetation present.
	7. Canopy Cover 60-100%	- Vegetation predominantly young coniferous but includes deciduous type
	8. Canopy Cover 20-59%	- Mixture of exposed soil and undifferentiated vegetative cover.
	9. Canopy Cover 0-19%	- Non Vegetated clearcuts. Vegetation predominantly forbs.
	10. Canopy Cover 0%	- Clearcuts established since August 7, 1978. Non vegetated.
	10A. Canopy Cover 0%	- Clearcuts established during 1978.
V	Other Classes	
	11. Burned Areas	- 11(8) implies burned area with vegetation canopy cover of 20-59%.
	12. Lakes, Small Lakes	
	13. Rivers	
	14. Tidal Flats	
	15. Subalpine and Alpine	- Dominated by bare rock. May be minor components of stunted trees.
	16. Avalanche Tracks	- Dominated by deciduous vegetation.
	17. Snow and Ice	
	18. Rock Slide	

/ The component in front of the symbol is more abundant than the one that follows (55-75% / 30-45%).

// The component in front of the symbol is considerably more abundant than the one that follows.

--- Approximate boundary used when shadows obscure detail.

(#) Area measurements of units in hectares are written in fine print. Class numbers appear in bold print.

NOTE: THIS MAP WAS PRODUCED BY VISUAL INTERPRETATION OF 1:140,755, SEPTEMBER 9, 1980, AND 1:500,000 AUGUST 7, 1978 LANDSAT IMAGES. FIELD WORK WAS NOT CARRIED OUT DURING THIS PROJECT.

LANDSAT INTERPRETATION and MAPPING by: KENT WATSON, INTERNATIONAL RANGE REMOTE SENSING LTD., for B.C.F.S.

LEGEND

LANDSAT IMAGE ANALYSIS; SAYWARD WILDLIFE HABITAT

MAPPING UNIT	UNIT SYMBOL	UNIT DESCRIPTION	LANDSAT IMAGERY CHARACTERISTICS[1]
			*1302 - MSS contrast stretch system
LANDSCAPE UNITS			
Deep water bodies	L	deep inland water bodies; lakes	dark blue
Shallow water bodies	Sw	shallow inland water bodies; also river beds	very light greenish blue
Shore features	S	tidal flats, beaches, estuaries	dark grayish red and light greenish blue
Snow	*		white
Alpine	m	rock, alpine vegetation; scattered trees in association with snow and subalpine map units	light grayish brown, light reddish brown, medium gray
Avalanche tracks	\	shrub growth on avalanche tracks cutting through surrounding forest vegetation	strong yellowish pink
Land slides	|	recent mobile earth movements which have not revegetated	light greenish blue
Rock	R	exposed rock surface other than alpine	medium gray
HABITAT UNITS			
Clear cut and recently logged	B	no indication of regeneration, may have significant areas of exposed soil	light grayish green
Partial Regeneration	PR	complex of coniferous and deciduous regeneration with areas of exposed soil or very sparse regeneration	complex pattern of light grayish green and dark yellowish pink
Young immature	I_y	regeneration of coniferous and deciduous trees and/or deciduous ground cover upon canopy	medium yellowish pink to dark yellowish pink
Immature	I_o	well established coniferous regeneration, some minor inclusions of deciduous trees caved canopy	near deep yellowish pink
Young mature	M_y	closed canopy, coniferous forest, aged 40 to 80 years	grayish red, light grayish red with bedrock near surface
Mature	M_o	closed canopy, coniferous forest, aged 80[+] years	range of colours (influenced by shadow) dark grayish red, dark red, grayish red or medium red
Scrub	S	scattered mature coniferous with dense scrub ground cover	colour pattern produced by combination of grayish red, light reddish brown, and grayish pink
Sub Alpine	SA	predominantly deciduous shrubs with few scattered coniferous trees, and some exposed rock	colour pattern produced by combination of light reddish brown and gray yellowish pink
Deciduous	D	dominantly deciduous vegetation	strong yellowish pink to dark yellowish pink
Wet lands	w	bogs, fens and marshes	strong yellowish pink, often associated with open water
Fields	F	cleared land no longer used for forestry purposes	brownish pink and grayish yellowish pink
HABITAT COMBINATIONS			
equal proportions	,	equal areas of each type, i.e., I_y, S	individual habitat types, distinguished by colour but pattern of units too small to separate
unequal proportions	/	habitat texture to left of / greater than habitat texture to right, i.e. I_y/S	individual habitat types, distinguished by colour but pattern of units too small to separate
influenced by	-	used with bedrock only; habitat feature shows to influenced by bedrock at or near the surface, i.e., $\frac{S}{R}$	colour of habitat texture modified by grayish colours and paler values

FIGURE 3

WILDLIFE HABITAT MAP LEGEND FOR VISUAL

MAP: J. BUNNING, ANALYST

SAYWARD WILDLIFE HABITAT MAPPING PROJECT

Mapping Base: LANDSAT Bands 4,5,& 7; paper print

Analysis and Compilation by: J.H. BUNNING

Date: November 1981

SCALE 1:125,000

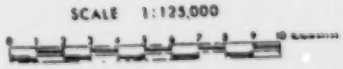

FIGURE 4
WILDLIFE HABITAT MAP LEGEND FOR THEMATIC MAP: G. TOM_INS, ANALYST

PLATE 3 CLASSIFICATION RESULT A FORESTRY-RELATED CLASSES SCALE 1:125 000	PLATE 4 CLASSIFICATION RESULT B FORESTRY-RELATED CLASSES SCALE 1:125 000
RED:	RED:
UNVEGETATED CLEARCUT	BOG, MARSH, FEN
PURPLISH RED:	PURPLISH RED:
VEGETATED CLEARCUT, (GRASS AND SHRUBS)	SHALLOW WATER
PURPLISH BLUE:	PURPLISH BLUE:
VEGETATED CLEARCUT, (YOUNG CONIFERS)	DEEP WATER
WHITE:	WHITE:
DECIDUOUS FOREST	ALPINE/SUB-ALPINE GRASSLANDS
YELLOW:	YELLOW:
MIXED FOREST	SHADOW
GREEN:	GREEN:
MATURE CONIFEROUS FOREST	ALPINE SHRUBS/AVALANCHE ZONES
LIGHT BLUE:	LIGHT BLUE:
OVERMATURE CONIFEROUS FOREST	ROCK UNDIFFERENTIATED
BROWN:	BROWN:
UNCLASSIFIED (SEE PLATE 4)	UNCLASSIFIED (SEE PLATE 3)

DESCRIPTION OF WILDLIFE HABITAT MAPPING TECHNIQUES

Colour Additive Viewer (CAV) Analyst: E. Kent Watson

This technique of mapping involves the use of Landsat imagery in the form of positive transparencies in conjunction with an optical instrument known as the Colour Additive Viewer (CAV). The CAV projects different colours through the Landsat transparencies onto a screen. The use of various coloured filters in the CAV increases the contrast between landscape features on the transparency thereby providing better recognition of wildlife habitat types. Mapping is generally done directly from the CAV Screen onto mylar sheets. However, cibachrome prints which are "hard copies" of the CAV transparency enhanced imagery were made. The cibachrome prints allowed Watson to complete the mapping assignment at his Kamloops office (The nearest available colour additive viewer to Watson was located in Edmonton, necessitating trip from Watson's base in Kamloops to Edmonton in order to complete the assignment).

The Landsat imagery supplied to Watson was extremely dark when displayed on the CAV screen. Consequently he was unable to use the proposed CAV technique and had to alter his approach. The method employed was similar to the Landsat paper print visual analysis done by John Bunning. A complete description of the technique employed by Watson (1981) to produce the modified CAV wildlife habitat map is presented in Appendix A. A summary of the main steps in the modified "CAV" technique is presented below.[Note: The term modified CAV technique is used in this report because although the production and utilization of cibachrome prints for mapping is technically considered to be using the CAV; this step was not identified or proposed for comparative analysis in the working plan (Sadoway, 1980b)].

DESCRIPTION OF WILDLIFE HABITAT MAPPING TECHNIQUES

* Black and white aerial photographs were examined to overview main Forest cover and landscape features of the study area, and to develop a classification.

* 1980 (Sept. 9) Landsat transparencies were prepared for the Colour Additive Viewer.

* The imagery on the CAV screen was examined.

* Two Cibachrome prints, (scale, 1:50 000) were prepared directly from the CAV screen using bands 4, 5 & 6 with blue, green and red filters. This step was necessary to lighten the image and to facilitate mapping from the print.

* Wildlife habitat types were mapped from Cibachrome prints.

* A draft map was checked against a 1978 Cibachrome print of the same area (scale, 1:500 000) [Note: This print was from K. Watson's personal files: it was used because the 1980 Landsat transparencies were too dark for mapping].

* the final wildlife habitat map was drafted on mylar and the area of each wildlife habitat unit was measured with a planimeter.

Visual Analysis of Landsat Paper Prints, Analyst: John Bunning

Wildlife habitats were mapped by placing a clear acetate sheet over the Landsat paper print (scale, 1:125 000) and delineating habitat types according to colour, tone and texture. Types were

interpreted at four levels of recognition (Bunning, 1981. Appendix B).

Level I

At level I, obvious differences between strongly contrasting colours were separated into different units.

Level II

White and gray "colours" were identified as snow and rock, respectively. Blue was identified as water and green corresponded to sparsely vegetated or bare soil and to water. Reds were identifed as vegetation and subdivided as follows:

* pink -- immature forest
* red -- mature forest

Level III

At Level III, wildlife habitat types were defined according to the range of colour values and chromas within a colour. Accordingly, a number of different habitat types were defined. These types were then "calibrated" by reference to large scale black and white aerial photographs. Based on this calibration, final habitat types were defined and limits were established according to ranges of colour.

A set of centroid colour charts published by the Inter-Society Colour Council and the National Bureau of Standards (ISCC-NBS) were used as an aid in defining colours. The ISCC-NBS system is specifically designed to define colours most commonly found in colour photographic imagery. Each chart consists of a series of colour chips defined on the Munsell scale of hue

(primary colour), value (lightness) and chroma (departure from neutral).

Black and white vertical aerial photographs were viewed stereoscopically with a fixed-mirror magnifying stereoscope to calibrate Level III map types. Interpretation was aided further by reference to B.C. Ministry of Forests forest cover maps to determine stand ages where necessary.

Level IV

Definition of map units at Level IV represents a departure from the systematic approach. Level IV mapping relied mainly on the interpretive skill and judgement of the analyst. For example, areas of the paper print which were partly obscured by cloud or shadows and complex map units were identified at this level.

For areas obscured by cloud or shadow the visual analyst made reference checks to aerial photography and type lines were approximated based on the surrounding visible habitats and existing patterns of nearby types.

Complex habitat types (such as the habitat combinations) were defined where two distinct types could be identified from the Landsat imagery but were too small to be mapped at the 1:125 000 scale; and when two or more distinct colours occurred in a unique texture or pattern and individual types could not be interpreted from the print.

DESCRIPTION OF WILDLIFE HABITAT MAPPING TECHNIQUES

Digital Analysis of DICS Computer Tapes (Thematic Map), Analyst: Geoff Tomlins

In general, digital analysis is computer mapping of the land and water features based on their reflective values. The Landsat data used in this analysis were from geometically corrected tapes (DICS).

The first step in the analysis was to locate training sites from vertical black and white aerial photographs. These training sites represent selected forest cover types and landscape features which were used then to determine and verify the spectral signatures.

Each spectral signature corresponds to a wildlife habitat type. The resultant classification system was then applied to the entire Landsat image.

The product is a detailed coloured photographic map with every pixel classified. A pixel represents a 50m x 50m area of the landscape.

Complete details regarding the principles and methods of digital analysis are presented in Tomlins (1981) (Appendix C).

3

METHODS OF MAP EVALUATION

A comparative analysis of the wildlife habitat maps produced by the CAV, visual and digital methods was conducted to determine the accuracy, cost effectiveness and general utility of the maps.

ACCURACY EVALUATION

The accuracy, or how well each map depicts the various landscape features habitat types of the study area, was evaluated by an office and field check. Accuracy is defined as how exactly the mapped wildlife habitat types depicts the various forest cover categories and other landscape features in the study area.

Office Check

Each analyst had prepared a classification system or legend, which was appropriate for his map. This legend reflected the number and kind of wildlife habitat types apparent and mappable on the Landsat image. In order to evaluate three maps with

different legends, a table of legend equivalents was prepared (Table 1). This table was used to equate the three map legends prior to evaluating the accuracy of each map in the office and field checking phases of the analysis.

The office check was conducted to overcome the problem of limited access to parts of the study area.

An overlay was prepared by drafting a line grid pattern on clear acetate. This overlay was designed to cover the mapped areas at a nominal scale of 1:125 000. The lines of the grid were then numbered from 0 - 100 along the X and Y axis. A total of 50 sample locations were selected by generating 100 random numbers. The first random number was plotted along the X axis: the second random number along the Y axis. The sample location was the X, Y intersect.

The fifty sample locations were marked on each wildlife habitat map and compared to published sources of information (i.e. B.C. Ministry of Forests, Forest Cover maps, black and white aerial photos, ortho photos and Landsat paper prints which were available at scales of 1:125 000 and 1:250 000).

One point, was awarded for each correct classification of wildlife habitat types. A maximum score of 50 points per map was possible.

The total area of wildlife habitat and landscape features mapped in the study area was determined to be 332850 ha. This figure was obtained by digitizing the entire area contained within the study area boundaries on 1:250 000 scale NTS maps. The area total was used as a standard to which the three analysts area totals could be compared.

Table 1

LANDSAT WILDLIFE HABITAT MAP

LEGEND EQUIVALENTS

	CONIFEROUS FOREST			MIXED FOREST		LOGGED & REGENERATING				WET		ALPINE & SUBALPINE		OTHER				COMBINATIONS
THEMATIC	OVER-MATURE	MATURE CONIFEROUS FOREST		DECID. FOREST	MIXED FOREST	VEG. CLEARCUT	VEG. CLEARCUT	UNVEG. CLEARCUT		BOG, MARSH FEN		AVAL. ZONE, ALP SHRUBS	ALPINE / S.ALPINE GRASSLANDS	WATER Shallow Deep	ROCK	SHADOW		
	Light blue	Green		White	Yellow	Purple-blue	Purple-red	Red		Red		Green	White	P.red P.blue	Light blue	Yellow		
VISUAL	MATURE	YOUNG MATURE		DECID. FOREST		IMMATURE	YOUNG IMMATURE	PART REGEN	CLEARCUT REC. LOGGED	WETLAND BOG MARSH	SHORE FEAT.	SUB-ALPINE	ALPINE	WATER Shallow and Deep	ROCK and SNOW	SCRUB	FIELDS	I_2, D M_1, M_2 I_2/D D/I_2 M_1/I_1 M_1/D $M_2/\bar{x}$ M_2/R
	M_2	M_1		D		I_2	I_1	PR	⊖	W	S	SA	♣	L, SW	R	$\bar{x}$	F	
CAV	OVER-MATURE	MATURE	OLD SEC. GROWTH CONIFER. FOREST	OLD SEC. GROWTH DECID FOREST	CAN. COVER 60-100 % DECID.	CANOPY COVER 20-59 %	REC. 2nd GROWTH 60-100 % COVER		CANOPY COVER 0-19 %	TIDAL FLATS		AVAL. TRACKS 16 SUBALPINE & ALPINE		LAKES RIVERS	SNOW ICE and ROCK	BURN		4/5 5/4 6/7
	1	2	3	5	6	8	4 & 7		9, 10, 10_A	14		15		12, 13	17, 18	11		

METHODS OF MAP EVALUATION

Field Check

Each wildlife habitat map was checked against a detailed set of field notes and 35mm colour prints obtained on a field survey of the study area conducted by W.G. Biggs and J.T. Standish of Talisman Land Resource Consultants during March 1982.

A total of 21 road transects (Figure 5) were identified on black and white aerial photography, photomosaics and forest company access road maps before going into the field. The transects were selected because they intersected most of the wildlife habitat types mapped and because the roads were the only available ground access to most sections of the study area. Wildlife habitat data and other information germane to the accuracy analyis were tape recorded in the field then transcribed.

All road transects were started at a major recognizable landscape feature (eg. bridge or intersection) to insure that the starting point of the transect could be recognized on aerial photos or maps.

In the field, the vehicle odometer was reset to 0 at the beginning of each transect and every major wildlife habitat type was recorded on both sides of the road along with the kilometers. This method of field data collection was considered to be effective as a continuous strip record of wildlife habitats along the transects covered all habitat types of the transect including small important habitats such as mature coniferous forest leave strips, fire guards and wetlands which could otherwise be missed. A photographic record was obtained

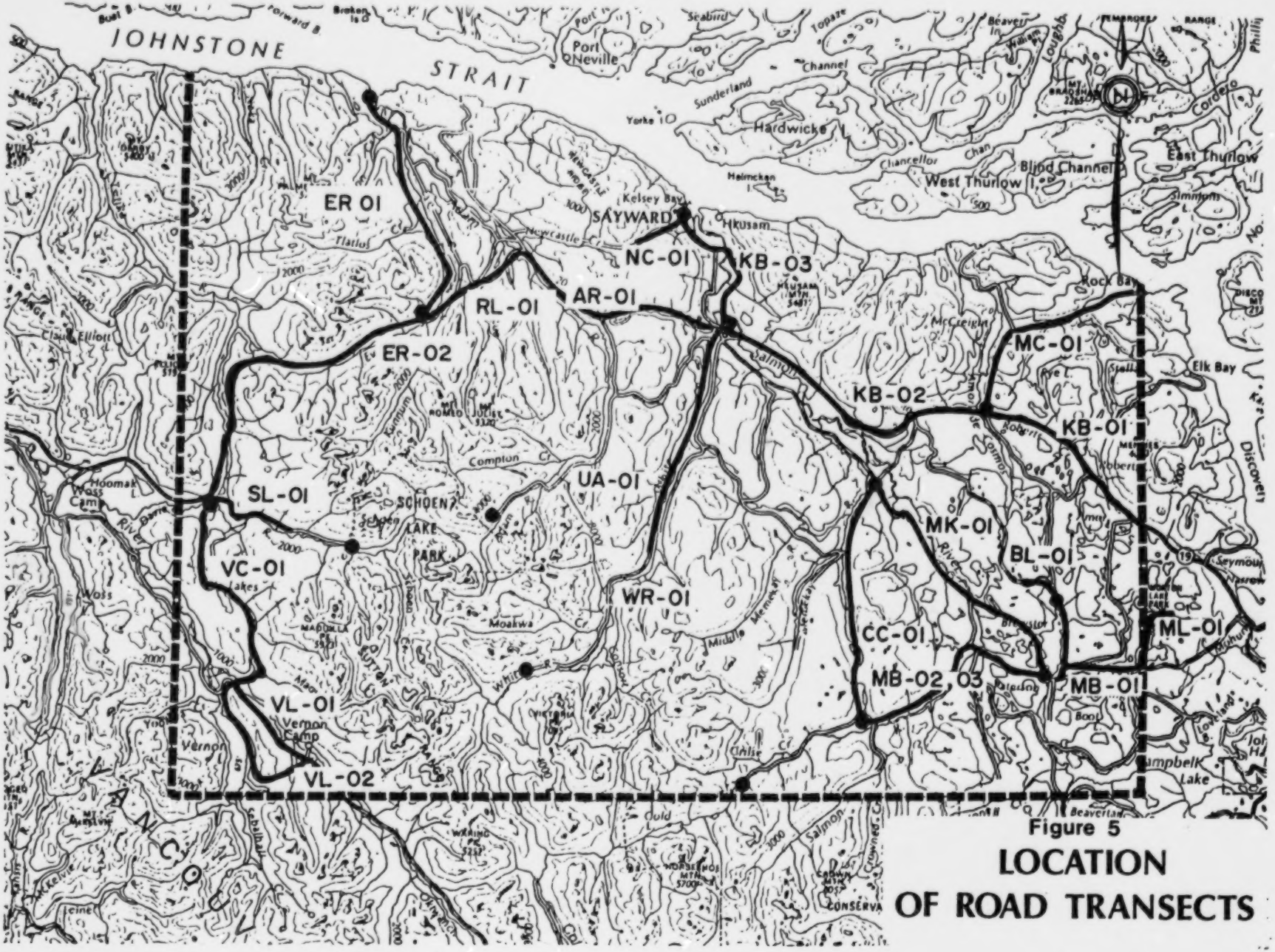

Figure 5

LOCATION OF ROAD TRANSECTS

by taking 35mm prints of representative habitat types along each of the transects.

The vegetation resources of each habitat type encountered along the transects were described. This description included physiognomic description, notes on past or present land-use, estimated age of stand and brief floristic description.

After field tapes were completely transcribed to give a continuous record of habitat conditions along the road transect then every second entry was selected as a sample point. A total of 120 sample points were used for the field check analysis.

Habitat descriptions and field locations of sample points, and colour photographs of typical habitat types were recorded on a standard form (Appendix D). These forms were filed with at the Research Branch, B.C. Ministry of Forests, Victoria.

The Thematic and the visual maps were prepared at a scale of 1:125 000. The CAV map was prepared at a scale of 1:148,755. To allow for the overlay, accurate plotting of transects and location of sample points the CAV map was photographically enlarged to the 1:125 000 scale and a new mylar produced.

An overlay outlining the 21 transect lines was prepared and distances in 0.1 km intervals was scaled along each transect with a map measurement wheel.

The wildlife habitat types of each wildlife habitat map were compared to the field vegetation descriptions at the selected sample points. A score of one point was awarded for each correct identification. The accuracy of the three methods was

determined by comparing the cumulative score of the three analysts. A total of 120 points was possible for each map.

This method of field checking was considered effective for the following reasons:

* it allows for the evaluation of the accuracy of maps with numerous small habitat units (eg. Thematic);

* the road transects were generally through the most diverse and important wildlife habitat types of the area. (e.g. lower slope regenerating clearcuts and lowland habitats);

* access was difficult elsewhere in the study area;

* the method allowed for the sampling of a large number of sample points throughout the study area; and

* exact map locations would otherwise have been costly to pin-point in the field

User Survey

A four page questionnaire was prepared by Talisman after discussion with the project coordinators to determine the utility of the wildlife habitat maps produced by the three analysts and to obtain other information regarding classification systems and map presentation. A total of nine (9) biologists and foresters were surveyed. These individuals were selected because of their interest in wildlife habitat

mapping and their knowledge of the study area. A copy of the questionnaire is presented in Appendix E.

Cost Analysis

The total costs of map production of the three techniques was estimated by calculating:

* professional & technical services at 1981 rates specified by the analysts (Note: the time and overhead costs incurred by each analyst to prepare his report were not included in the calculation).

* any travel expenses incurred by the analysts were included when travel expenses were considered vital to map production. Travel costs to attend meetings and to obtain materials were not included by the comparison analysts.

* the cost of all mapping materials and computer time at the rates and costs suggested by the analysts was included in the analysis.

4

RESULTS OF EVALUATION

Office Check

The CAV map was found to be the most accurate with a score of 90%, followed closely by the Visual map with an accuracy score of 88%. The Thematic map scored 68%. The ninety-five percent confidence intervals to the nearest 1% accuracy are:

* CAV - 82% to 98%

* Visual - 79% to 91%

* Thematic - 55% to 81%

The details of the office check are presented in Table 2.

Field Check

The results of the field check were similar to those of the office check. The modified CAV map was found to be the most accurate with a score of 89%. The Visual map, scored 78%. The thematic map was the least accurate with a score of 58%.

Table 2

RESULTS OF LANDSAT
ACCURACY TEST - OFFICE CHECK

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	METHOD	SCORE
	✓	✓	✓	✓	x	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	✓	✓	✓	✓	✓	✓	✓	✓	x	✓	x	✓	x	✓	x	✓	✓	✓	MODIFIED CAV	45 / 50
HABITAT TYPE →	M CF	I CF	SA	M CF	OM	M CF	M CF	M CF	M CF	M CF	M CF	M CF	M CF	M CF	M CF	RV	I CF	SA	M CF	I CF	I CF	M CF	M CF	RL	M CF	M CF	M CF	I CF	M CF	M CF	I CF	OM	M CF	I CF	M CF	M CF	M CF	I CF	M CF	RL	M CF	OM	M CF	I CF	M CF	OM	M CF	M CF	M CF	M CF		90 %
	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	✓	✓	✓	x	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	x	✓	✓	✓	✓	✓	✓	x	VISUAL	44 / 50
	M CF	I CF	SA	M CF	SA	M CF	M CF	M CF	M CF	M CF	I CF	M CF	M CF	M CF	SA	D	I CF	AL	M CF	I CF	I D	M CF	M CF	RL	M CF	SA	M CF	I CF	M CF	M CF	I CF	RL	M CF	I CF	M CF	M CF	M CF	I CF	M CF	RL	M CF	M CF	SA	M CF	M CF	M CF	SA	M CF	M CF	M CF	SA		88 %
	✓	x	✓	✓	✓	✓	✓	✓	✓	x	✓	✓	✓	✓	✓	x	✓	x	✓	✓	x	✓	✓	✓	x	✓	✓	x	✓	✓	x	✓	✓	x	x	✓	✓	x	✓	✓	x	✓	x	x	✓	✓	✓	x	✓	x	THEMATIC	34 / 50
	M CF	AL	SA	M CF	SA	M CF	M CF	M CF	M CF	SH	M CF	M CF	M CF	M CF	M CF	AL	I CF	SH	M CF	I CF	BG	M CF	M CF	RL	SH	M CF	M CF	AL	M CF	M CF	M CF	RL	SH	RL	I CF	M CF	M CF	M CF	M CF	RL	SH	D	SH	AL	M CF	SA	M CF	D	M CF	RL		68 %

✓ Correct – one point scored

x Incorrect – score 0

LEGEND FOR HABITAT TYPE SYMBOLS

AL	Alpine	BG	Bare Ground
M CF	Mature coniferous forest	D	Deciduous, second growth
I CF	Immature coniferous forest	OM	Overmature
SA	Subalpine	RV	River
RL	Deciduous recently logged	SH	Shadow

RESULTS OF EVALUATION

Ninety-five percent confidence limits for accuracy, rounded to the nearest 1%, are:

* CAV - 83% to 95%

* Visual - 72% to 86%

* Thematic - 48% to 67%

A summary of the field check results by road transect is presented in Table 3.

User Survey

A total of nine questionnaires were completed. A summary of the scores assigned to each map by individual reviews is presented in Table 4.

The Visual map rated the highest in total points, followed closely by CAV. The Thematic map were consistently rated the lowest. Data from the questionaires was also analyzed through ranking methods (Moroney, 1951). The Coefficient of Concordance for ranked data is 0.82 and is statistically significant, indicating a high degree of agreement in the overall rankings by the nine respondents.

Reviewer comments and criticisms are discussed further in Chapter 5.

TABLE 3

SUMMARY OF THE FIELD CHECK SCORES

LANDSAT ACCURACY TESTS

TRANSECT	MAX SCORE	MAPPING METHOD			NO. OF HABITAT CLASSES ALONG TRANSECT									
		CAV	VISUAL	DIGITAL	I CF	M CF	D	MIXED	DIST CULT	C.CUT	ROCK B.GR.	REG C. CUT	POND. WL	GR. MEAD.
KB-01	7	7	7	4	7									
MC-01	9	7	8	4	6	1	2							
KB-02	4	3	4	1	2	1	1							
KB-03	2	1	2	0				1	1					
NC-01	3	3	3	3	1	2								
WR-01	13	9	8	9	4	6				2		1		
AR-01	6	3	3	5	1	2	1			1		1		
UA-01	2	1	1	0				1				1		
RL-01	4	4	3	4	1	2				1				
ER-01	10	7	9	6	2	3		1	1		1	2		
ER-02	8	7	6	4		3				3		1	1	
SL-01	4	4	4	1	2			1				1		
VC-01	7	5	5	4	1	1			1			2	2	
VL-02	10	7	8	5	1	5		1				2	1	
VL-01	3	1	1	2	1	1		1						
ML-01	2	1	1	1	1								1	
MB-01	3	2	2	2	1						1		1	
BL-01	3	1	2	3	1	1						1		
MB-02/03	8	6	6	4	3	2		1					2	
CC-01	8	6	6	4	2	2				2		2		
MC-01	4	3	4	3	1			1				1		1
TOTAL	120	107/120	93/120	69/120	38	32	4	8	3	9	2	15	8	1
SCORE (% of sample)	100%	89%	78%	58%	(31.6%)	(26.6%)	(3.3%)	(6.6%)	(2.5%)	(7.5%)	(1.6%)	(17.5%)	(6.6%)	(0.8%)

TABLE 4

USER SURVEY RESULTS

(Where 1= very poor, 2= poor, 3= acceptable, 4= good, 5 = very good)

	KIM BRUNT			RICK DAVIES			DON EASTMAN			IAN HATTER			DOUG JANZ			BRIAN NYBERG			LES PETERSON			LINDA STORDEUR			JOHN YOUDS		
*	C	V	T	C	V	T	C	V	T	C	V	T	C	V	T	C	V	T	C	V	T	C	V	T	C	V	T
A. READABILITY	3	3	2	3	4	2	4	3	2	3	4	3	3	4	2	3	2	4	3	4	5	4	3	2	3	2	4
B. UTILITY FOR WILDLIFE/FORESTRY RESEARCH	3	3	2	1	1	1	4	5	1	3	4	3	3	3	2	2	2	1	3	3	2	3	4	1	3	4	2
C. SUIT OF LEGEND	4	3	2	4	5	2	5	4	1	4	2	2	4	4	2	3	4	1	4	5	3	4	4	2	3	4	2
D. EASE OF HANDLING	3	3	3	N/A			4	4	4	3	3	2	3	3	3	3	3	4	4	4	5	3	3	3	3	3	2
E. PERCEIVED ACCURACY	3	3	1	2	3	2	N/A			3	3	2	3	4	1	3	4	2	3	4	2	3	4	2	3	4	2
F. CLARITY	3	3	2	4	3	2	4	3	2	2	3	4	3	3	2	3	2	3	4	4	3	4	3	2	3	3	3
G. ABILITY TO MAKE CHANGES	4	4	2	3	3	1	3	3	2	3	4	2	2	2	4	4	4	1	4	4	1	2	3	1	N/A		
H. USE IN FIELD	4	4	1	1	1	1	4	4	2	3	3	2	3	3	2	3	3	1	2	2	3	4	4	2	2	2	2
I. USE IN OFFICE	4	4	3	3	3	2	4	4	4	3	3	3	3	3	3	3	3	5	3	3	4	N/A			3	4	2
J. REPRODUCIBILITY	4	4	2	5	5	2	5	5	2	3	3	2	2	2	2	4	5	1	5	5	2	4	4	1	N/A		
K. COMPATIBLE WITH OTHER BASES	3	3	2	1	1	1	4	3	2	2	3	2	N/A			4	3	2	3	3	3	2	4	4	2	2	2
TOTAL	38	37	22	27	29	16	41	38	22	32	35	27	29	31	23	35	35	25	38	41	33	33	36	20	25	28	21
	55	55	55	50	50	50	50	50	50	55	55	55	50	50	50	55	55	55	55	55	55	50	50	50	45	45	45
SCORE %	69	67	40	54	58	32	82	76	44	58	64	49	48	62	46	64	64	45	69	75	60	66	72	40	56	62	47

SUMMARY

C	V	T	
69	67	40	
54	58	32	
82	76	44	
58	64	49	
48	62	46	
64	64	45	
69	75	60	
66	72	40	
56	62	47	
565	600	403	TOTAL SCORE
63%	67%	45%	AVERAGE SCORE

* C. Modified CAV
V. Visual
T. Thematic

RESULTS OF EVALUATION

Cost Analysis

The total cost of map production was calculated based on cost-time estimates supplied to Talisman by individual analysts.

All professional and technical services at 1981 charge-out rates specified by each analyst and materials necessary to produce the wildlife habitat maps have been included in this estimate.

MODIFIED CAV

Professional Services by Task	Days	Rate	
- preparation and attempts to map on CAV	3.63	250/day	907.50
- legend development and mapping	2.84	250/day	710.00
- polygon measurement (planimeter)	2.78	250/day	695.00
- final map drafting	3.28	250/day	820.00
	SUBTOTAL		$3,132.50

Disbursements	
- travel expenses mileage	$ 290.00
- accomodation and living allowance	275.00
SUBTOTAL	$ 565.00
GRANDTOTAL	$3,697.50

RESULTS OF EVALUATION

VISUAL ANALYSIS

Professional Services by Task

- preparation, planning and review of data	0.4	225/day	$ 90.00
- assemble equipment, materials and register acetate to imagery	0.27	225/day	60.75
- legend development and interpretation	0.43	225/day	96.75
- mapping	2.18	225/day	490.50
- polygon measurement, digitizing	1.4	225/day	315.00
- prepare summary table	0.4	225/day	90.00
- final map drafting	1.06	225/day	238.50
- final checking	0.13	225/day	29.25
	SUBTOTAL		$1,410.75

Disbursements

- materials		$ 18.88
- rental of digitizing equipment (10.5 hrs. @ $25.00/hr.)		262.50
	SUBTOTAL	$ 281.38
	GRANDTOTAL	$1,692.13

DIGITAL ANALYSIS

Professional and/or Technical Services by Task

- project management	1	400/d	$ 400.00

- interpretation of training sites and accuracy evaluation samples	4	300/d	1,200.00
- delineation of training sites	2	400/d	800.00
- acquisition of spectral reflectance data	1	400/d	400.00
- analysis of spectral reflectance data	1	400/d	400.00
- classification	1	400/d	400.00
- accuracy evaluation	4	300/d	1,200.00
		SUBTOTAL	$4,800.00

Disbursements

- computer time	24 hrs. @ $90/hr	$2,160.00
- travel expenses		300.00
- materials		600.00
	SUBTOTAL	$3,060.00
	GRANDTOTAL	$7,860.00

The total area of the study area was estimated to be 332,850 ha. The total area standard was determined by digitizing the study area boundaries plotted on NTS maps.

The modified CAV map area total was determined to be 337,202 ha (Watson, 1981). This area was 4352 ha more than the standard, a difference of approximately 1.3%.

The Visual map area total was calculated to be 322,430 ha (Bunning, 1981). This total area varies approximately 3% from the standard.

The Thematic map area total was 348,095 ha. This difference of 15245 ha varied 4.6% from the standard.

5
DISCUSSION

Accuracy, utility and cost effectiveness were the main criteria considered in the evaluation of the three methods of wildlife habitat map production based on Landsat imagery.

Every effort was made to objectively evaluate the three methods.

Several assumptions regarding the comparison of the three mapping methods were made at the outset of the study.

1. Each map produced was the best product possible given the limitations of the method employed. That a state-of-the-art map would be provided for this evaluation.

2. Each map is representative of each mapping technique.

3. The classification system developed by individual analysts was appropriate and adequately represented habitat resources that could be mapped from Landsat imagery.

4. The mapping methodology is repeatable.

5. The study area boundaries were identical and the same land area was mapped by each analyst.

Unfortunately, several assumptions were inaccurate due to circumstances beyond the control of the analysts or the Ministry of Forests project coordinators.

The Thematic map was not produced using state-of-the-art techniques. Tomlins (1981) reports that the accuracy would have been greatly improved by using current field inspection information for locating representative training sites. The use of aerial photographs instead of field inspection data was, however, done for two reasons:

1. this insured that each analyst used the same data base; and

2. the cost of field inspection (ground truthing) is extremely high (Sadoway, pers. comm).

All Landsat analyses would probably have been improved if field inspections had been employed. The accuracy of the Thematic map therefore reflects the dependency of digital analysis on current ground truthing information.

Atmospheric effects such as light cloud, haze and a con-trail of a jet aircraft also reduced the accuracy of the digital analysis. New techniques to increase the accuracy of Thematic maps are continually being developed and tested. Therefore, the low scores obtained by the digital mapping system are a result

of technical problems, many of which are currently being investigated and resolved.

The CAV mapping method proposed by Watson (Sadoway 1981) could not be done as the Landsat images supplied by the Prince Albert Remote Sensing Centre were extremely dark when displayed on the CAV screen. This lack of clarity rendered map production directly from the CAV screen impossible. The CAV map was therefore produced using the CAV for legend development only. Visual interpretation of a cibachrome was used for boundary delineation. Therefore, this wildlife habitat map is not completely representative of the CAV mapping method as outlined in the working plan (Sadoway, 1980b). This technical change caused difficulties in the comparitive analysis as the methods employed by Watson and Bunning were similar.

The classification systems developed by each analyst are believed to reflect the maximum detail of mapping possible by each method. However, the comparison of the three maps could have been more equitable, and the potential of each method for future use in habitat mapping could have been better assessed, if the analysts were required to map specific habitat types considered to be important by biologists knowledgeable of the habitat resources of the study area. (That is, if the same legend was given to each analyst before mapping).

The study area boundaries were virtually identical for the modified CAV and Visual maps. However, the Thematic map produced from analysis of Landsat Digital Image Correction System (DICS) data was found to be incompatible with the Canadian NTS map sheets. For example, the area covered by the Thematic map extended below the 50 parallel of latitude, the southern boundary of the study area. The total study area

figure provided in the Tomlin's (1981) report was therefore larger than it should have been, even after the area of the Landsat scene beyond the study area was digitized and subtracted from the original full DICS scene total.

An additional problem which made the evaluation of accuracy more difficult was the lack of a total area figure. A standard to be used to compare the visual and CAV maps was to be based on the digital computer generated measurement of the total study area hectarage. This total was not available because the computer could only calculate total areas of an entire Landsat scene and could measure specific parts of the scene. Therefore the total area of 332850 ha suggested by Bunning, from his digitization of NTS map sheets was used as standard.

The CAV map was presented at a scale of 1:148 755, while the Thematic and Visual maps were produced at 1:125 000. Although the Watson mylar was photographically enlarged to a nominal scale of 1:125 000 some distortion occured thereby making direct overlay and comparison of the three maps difficult.

The strengths and weaknesses of each mapping technique are discussed below.

Colour Additive Viewer (CAV), Analyst: Kent Watson

The visual mapping of wildlife habitats from a cibachrome print, or modified CAV method was generally considered to be the best of the three as it is inexpensive, accurate, and carefully done. It should be emphasized that this wildlife habitat map was not produced using the proposed CAV methodology.

DISCUSSION

The accuracy and costs would vary from one mapper to the next. An experienced professional analyst, such as Watson could produce accurate maps from Landsat imagery while a less experienced analyst may overlook subtle differences in colour and texture reducing the overall quality of the map.

The modified CAV map was well drawn, with attention to cartographic detail. It included the notation of polygon sizes in hectares, although this was not called for in the Terms of Reference (Sadoway, 1980b). This feature was considered to be an advantage by most reviewers.

One major, consistent reviewer criticism of the modified CAV map was that the use of numbers used to identify the various habitat types on the maps were distracting and difficult to read. Most reviewers considered colour to be the best method of identification of habitat types. Alphabetic symbols were also considered to be better than numbers as the letter symbols quickly become familiar and required less frequent cross-referencing to the legend.

Reviewer comments regarding the legend of modified CAV map were mixed and appeared to vary with individual intended uses of the map. Most reviewers considered modified CAV map legend to be adequate and the most useful of the three because age classes of regenerating stands were identified.

Paper Print Analysis (Visual), Analyst: John Bunning

The visual analysis of a Landsat paper print was a second to the CAV map in terms of accuracy. The Visual map was the least expensive map to produce. At a total cost of approximately

$1,700.00, the cost of the Visual map was approximately one half the total cost of the CAV map and less than one quarter the actual cost of production of the Thematic map. (It is recognized that the production costs CAV map would have been reduced to the level of the Visual map if the technical problems and travel costs were not incurred).

Although the Visual map and the CAV map were produced without any collaboration, they were found to be very similar with respect to the classification system developed and the overall accuracy. It appears as if the two qualified analysts were "seeing" many of the same landscape and wildlife habitat features on the Landsat print and their interpretations of these features were similar.

Bunning (1981) classified several large units of the map sheet as combinations of two habitat types. This aggregation of two habitat types was also done to a limited extent by Watson (CAV map). On the modified CAV map these types mainly represent mixtures of second growth coniferous forest and deciduous forest types. No habitat combinations were mapped by Tomlins, (Thematic map).

Two habitat types, the scattered mature coniferous forest with a dense shrub cover, or the scrub (X) type and mature coniferous forest/scrub combination (M2,X) type were mapped only by Bunning. The other analysts classified these habitats as mature or overmature coniferous forests. Black and white aerial photographs of these areas were examined by W. Biggs and were interpreted as mature and overmature coniferous forest types. Unfortunately these areas were inaccessible by road and no field descriptions are available to verify the mapped types.

DISCUSSION

Few reviewers commented on the combination of habitat types on the Visual or CAV maps. It appears that some complexing of habitat types could increase the value of the habitat map, although it is possible that habitat combinations unnecessarily clutter the map and are not required at a scale of 1:125 000 or smaller.

Several reviewers preferred the neatness and layout of the Visual map legend, although most considered the linework of the modified CAV map and the general quality of Watson's map drawing superior.

Digital Analysis (Thematic), Analyst: Geoff Tomlins

The Thematic map was found to be the least accurate and most costly of the three wildlife habitat maps evaluated.

The assessment of map accuracy and comparison of methods of visual map production to digital analysis was a difficult task because the format, habitat unit size, presentation and classification systems are very dissimilar. In addition the technology of digital mapping is evolving rapidly and many of the conclusions drawn here regarding the use of digital classification methods could be invalid before this report is published.

With these qualifications in mind, it was a widely held opinion that the Thematic map produced was difficult to read and unfamiliar to most reviewers. Most considered the classification scheme too broad to be useful for detailed studies. However, the spatial distribution and overview of the diversity of habitats in a large study area could be readily

observed by scanning the Thematic map(s). Virtually all reviewers considered the colour photographic presentation advantageous and superior to the blueprint type map produced by the visual and modified CAV methods.

The relatively low accuracy score of the Thematic map was caused by shadows on the Landsat scene, local atmospheric effects and the inadequate method of selecting training sites employed.

The problem caused by shadows on Landsat imagery can be overcome by a recently developed technique of digital terrain modelling (DTM). This technique would reduce the error caused by shadowing in mountainous terrain and allows for more accurate classification of habitat types The DTM technique is expensive and would substantially increase the cost of map production (Tomlins, pers. comm.).

Local atmospheric conditions such as light cloud and haze alter the spectral signature of landscape feature on the image and lead to the inaccurate identification of landscape features. Currently methods to to mask the features below local atmospheric disturbances are available. These techniquees could reduce inaccuracies but the extra step of visual interpretation of features under the masks must be done and will add also to the overall cost of map production (Tomlins, pers. comm.).

The use of aerial photos of different scales and ages for the selection of training sites was considered to be another significant cause for incorrect classification of wildlife habitat types on the Thematic map. This problem is addressed completely in Tomlin's (1981) report (Appendix C). This source

of error can be reduced by obtaining field descriptions of selected habitat types at or near the time of Landsat data acquisition. This field work would insure that the spectral signature of the training site is representative of selected habitat types to be analysed. Field work, especially in highly diverse inaccessible terrain as is found on Vancouver Island, would be costly and would significantly increase the total cost of map production.

Digital analysis of Landsat imagery is precise and repeatable because reflectance value of each pixel and the spectral signature of each specific training site within each Landsat image will be constant and therefore the analysis of Landsat data will be identical. Digital analysis precision is scene-dependent (i.e. date and geographic locality). The CAV and Visual methods of analysis are not as repeatable as classification decisions can vary with the experience of the analyst.

All digital Landsat DICS data are expected to be geometrically rectified and compatible with the Canadian National Topographic maps. This was found not to be the case for quadrants 92 LI and 92K4. Apparently other scenes have been incorrectly rectified (Tomlins, pers. comm.) and this has caused inaccuracies in the total area measurements for the Thematic map.

The reviewers surveyed reported that they could use the Thematic map to obtain an overview of habitat diversity, and for the analysis of habitat change through time and at a small scale. However, if the accuracy of the map could be improved the Thematic map could be useful for the delineation of small important habitats such as narrow riparian vegetation types, marshes and winter range habitat.

DISCUSSION

Problems Common to All Maps

All of the maps evaluated had several short-comings.

Virtually every reviewer thought that the maps would be more understandable if road networks and place names of major lakes and rivers could be placed on the map. The addition of these features would increase the readability of the map considerably.

The alpine, subalpine and rock classes on the maps were not accurately mapped due to poor boundary definition and because the landscape features of many of these areas were obscured by shadow. It therefore appears as if Landsat based habitat maps of flat or gently rolling terrain would probably be more accurate than maps of habitats in mountainous terrain.

The Landsat maps provide a good overview of the spatial distribution of habitat types over a large area. However, they are often not practical for the selection of study plots or particularly useful for wildlife management purposes.

6
CONCLUSIONS

This comparative analysis represents one of the first qualitative evaluations of the accuracy, utiilty and cost of wildlife habitat map production based on Landsat imagery.

Although the technical problems discussed in Chapter 5 have caused some difficulties in the assessment of the three mapping methods, several conclusions regarding Landsat as a base for habitat mapping are apparent.

1. Wildlife habitat maps produced from Landsat imagery are valuable for overview studies of large areas.

   They provide information on the spatial relationships of habitat types and may be important for regional mapping, strategic planning studies, monitoring or small scale mapping of distinctive habitat types (eg. snow cover studies).

2. Mountainous terrain with a high degree of habitat diversity can create several problems which decrease

the accuracy and utiity of Landsat based wildlife habitat maps.

Areas with low habitat diversity and low relief are probably more suited to Landsat based maps. All analysts had difficulty mapping sub-alpine and alpine habitats because shadows and steep terrain posed interpretation difficulties.

3. Locating study plots would be difficult due to the scale available and the lack of cultural features (eg. roads and place names).

The largest useable scale available to map wildlife habitat types from Landsat imagery is 1:125,000.

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APPENDIX A

REPORT OF KENT WATSON

(Note: Reproduced as submitted to Talisman for comparison analysis)

LANDUSE AND LAND COVER CLASSIFICATION AND MAPPING OF THE SAYWARD FOREST USING LANDSAT IMAGERY AND A COLOUR ADDITIVE VIEWER

by

Edward Kent Watson

INTERNATIONAL RANGE REMOTE SENSING LTD.

for

British Columbia

Ministry of Forests

1981

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INTRODUCTION

This project was conducted to determine the feasibility of using a Colour Additive Viewer (CAV) and Landsat imagery to map an area covered by four 1:50,000 NTS map sheets. Landsat mapping scale was to be approximately 1:150,000.

The major objectives were to develop a anologue Landsat mapping methodology and classification for the Sayward forest located on north eastern Vancouver Island. Area measurements and classification accuracy predictions were also required. The main deviation from standard remote sensing mapping proceedures was that this study was to be conducted without field work. All mapping classes were derived using visual, anologue, photo interpretation techniques.

While problems existed with the brightness quality of Landsat imagery provided by the Canada Centre for Remote Sensing (CCRS), they were solved by developing an alternate method of interpretation. It was concluded that Landsat imagery, produced at Two Times Lookup Table Values (2xLUT), used in a CAV and in conjunction with contact cibachrome prints, would provide an excellent method for mapping large areas from the imagery. Mapping, classification and area measurement accuracies were considered to be good to excellent. A total of fifteen man days were required to complete the interpretation, mapping and report.

LITERATURE REVIEW

Murtha and Watson (1975) mapped the progression of clearcuts on Southern Vancouver Island using sequential Landsat imagery and a Colour Additive Viewer. Eight mapping classes were described (Appendix A). Area measurements were not attempted because of reported image distortion problems. The authors speculated that "Precision processed imagery" might alleviate the distortion problem and lead to accurate area and boundary determinations.

Precision processed imagery is a reality and applications of Landsat imagery in other operational mapping projects have been conducted. Watson (1981a), on contract to B.C. Research, mapped the Canadian portion of the Flathead drainage basin, in south eastern B.C., using a 1:250,000 CCRS cibachrome image as a data base. An independent classification accuracy check was conducted by B.C. Research in 1981. Eighty-nine percent accuracy was obtained for Rocky Mountain Pine Beetle kill and an overall accuracy of 82-85% was obtained for fifteen classes (per. comm. Dr. Goeff Tomlins, B.C. Research).

Map boundaries were transfered to a 1:125,000 topographic map base using a Bausch and Lomb Zoom Stereo Transfer Scope (Watson 1981a). Boundary placement was concluded to be accurate. Landsat imagery was used to map a power line corridor (Watson 1981b). Boundaries were transfered to a

1:125,000 map sheet and then to a 1:50,000 map base using a Bausch and Lomb Vertical Transfer Scope. Transfering of Landsat data to topographic maps was not a difficult process and resulted in more accurate placement of units than thought possible.

METHODS

Materials

Materials supplied for this study included four 1:50,000 National Topographic Series (NTS) map sheets, black and white aerial photographs, their accompanying flight index maps, and four black and white Landsat positive transparencies (Table 1).

Table 1. NTS Map Sheets and Landsat Imagery Supplied for the Colour Addive Viewer Study.

NTS 1:50,000 Maps	Landsat Image Transparencies
1. 92K / 4	1. Band 4, green .5 - .6 microns
2. 92K / 5	2. Band 5, red .6 - .7 microns
3. 92L / 1	3. Band 6, NIR* .7 - .9 microns
4. 92L / 8	4. Band 7, NIR .9 - 1.1 microns

*NIR = Near infrared
Path 53 Row 25
Scene ID No. 09-09-80
Image Date September 9,1980
Scale 1:1,000,000

A July 7, 1978, 1:500,000 false colour infrared ciba-crome print, produced in 1978 by the author while employed

at the University of British Columbia (UBC), was used as "ground truth" data in the final mapping and classification phases.

Mapping and drafting was done with a .13mm Mars drafting pen. Clear plastic overlays and .033mm Draftar mylars were used in the mapping phase. A Gelman Planimeter was used to measure map unit areas.

Image Preparation

The black and white 1:50,000, 1:40,000 and 1:20,000 aerial photographs were examined to determine the number of classes expected to be identified on the Landsat imagery providing the area of each unit or class was large enough to be imaged by the Landsat system (Table 2).

Table 2. Classes initially identified on the aerial photographs as potential candidates for Landsat mapping.

Class	Class
1. Snow and Ice	13. Clearcuts - Vegetated
2. Avalanche Tracks	14. Clearcuts - Non Vegetated
3. Rock	15. Tree Islands in Clearcuts
4. Rock Slides	16. Logging Roads
5. Water	17. Burns
6. Tidal Flats	18. Agriculture Areas
7. Major Rivers	19. Hydro Lines
8. Floodplains	20. Damns and Reservoirs
9. Wet Meadows	21. Cities and Towns
10. Mature Forest	22. Air Strips
11. Immature Forest	23. Shadows
12. Deciduous Forest	

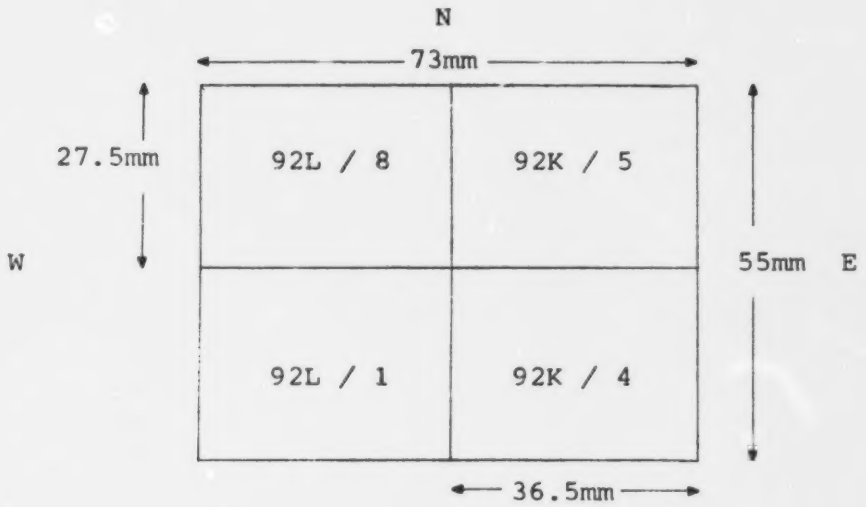
The NTS 1:50,000 maps were used to delineate study area boundaries on the band six Landsat image. This band was brightest and easiest on which to locate the study area boundaries. The boundaries were scored on the emultion with a sharp metal scribe. Nylon gloves were worn at all times when handling the imagery to avoid finger prints.

The study area portion was cut from the band 6 185cm image. Successive images were placed on a light table and taped securely with masking tape. The precut band 6 image was placed on each of the remaining images and orientated such that exactly the same areas were scored and cut along the same boundaries. The cut images were 55mm long in the north/south direction and 73mm in the east/west direction. The east/west dimention was too long to fit into the CAV* trays and the images were bisected along the central north/south axis (Fig.1).

The band 4, 5, 6 and 7 images were placed in their respective CAV trays. The images were loaded by holding them as they were to be viewed on the CAV screen and were then turned over east to west and placed in the trays. When displayed on the CAV screen the images were viewed in the correct orientation. The images were registered using the vertical, horizontal and rotational CAV controls.

Special mention and thanks is extended to the Alberta Center for Remote Sensing for use of their Colour Additive Viewer during this study.

Figure 1. Landsat image size used in the Colour Additive Viewer.



2x2 NTS 1:50,000 quadrant fits the CAV trays in the north/south direction but not in the east/west dimention. The images were cut along the central north/south axis. Two maps and cibachrome prints were produced from the CAV screen. The final map was produced by joining the two prints and maps. The above diagram is to scale.

Image Interpretation and Mapping

All four bands were extremely dark when displayed on the CAV screen. The green band, 4, was almost black with the only discernible class being newer clearcuts. Lakes and oceans could not be separated from land. Band 5, red, was the same as band 4 with the exception that the newer clearcuts were lighter than on the former image. Boundaries between young and old growth stands were visible if bare soil was associated with the younger stands. Water could not be separated from land on band five.

Band 6, near infrared, was the lightest but was also dark. Boundaries were fairly sharp between clearcuts and old growth stands. Many small lakes, less than 1.4 hectares, were not discernible because there was not the usual high contrast between water and forest stands. The coastline of Vancouver Island was difficult to delineate in places because stong north slope shadows obscured the boundary.

Band 7, near infrared, was darker than band 6 and was of a slightly different scale than the other three bands. This scale difference was a function of the satellite system (per. comm. Ian Sutherland, Alberta Remote Sensing Center). Boundaries between old and younger stands were not as sharp as those on band six.

A sheet of .003mm Draftar mylar was placed on the CAV viewing screen. A clear filter was used in combination with band 6 to map lakes, major rivers and the coastline. Recent clearcuts and differences between some vegetation units were also mapped with the former image/filter combination.

A green filter in conjunction with band 5 and a red filter combined with band 6 were used to produce a false colour infrared composite image on the CAV screen. This combination was used to rank vegetation classes, in terms of colour, from dark brownish red to light red and to delineate boundaries between more subtle units.

Bare soil surfaces and rock units were best displayed

and mapped by placing a red filter on band five and a blue filter on band six. Barren surfaces were displayed as red against blue vegetated units.

A tentitive classification was developed in conjunction with the interpretation and mapping phases. Thirty-five mm slides were taken with a Pentax LX camera equiped with a macro lens. Photographs were taken of the black and white band 6 image and of the colour infrared composite. These photographs were used for reference in the office.

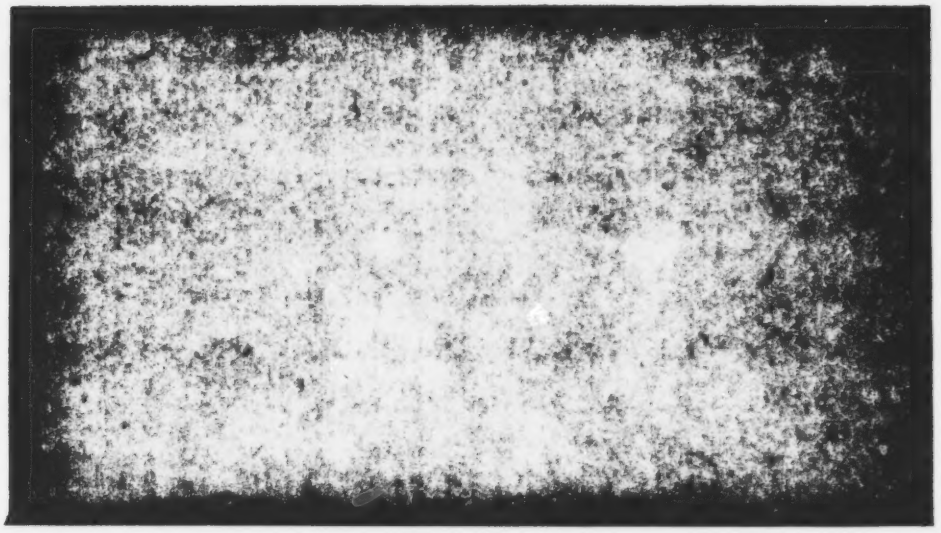
Two cibachrome prints were made directly from the CAV screen by Mr. Ian Sutherland in an attempt to lighten the false colour infrared scene. Bands 4, 5 and 6 were used with respective blue, green and red filters to produce the prints. The scenes were lightened somewhat and clearcuts on north slopes and near the image edges were more discernable (Fig. 2).

Comparison of the two cibachrome prints with the CAV screen images and maps suggested that greater boundary and classification accuracy could be obtained by mapping directly from the prints. Clear plastic overlays were placed on the prints and the study area was remapped. Remapping was done on a light table as illumination through the cibachrome prints made boundary delineation easier.

Black and white aerial photographs were used as "ground truth" to classify some of the mapped units. A cibachrome

Figure 2. Portion of a Landsat cibachrome print produced by the Alberta Remote Sensing Center in an attempt to lighten the dark CCRS imagery.

N

E  W

This image is reversed from left to right. North is at the top and west is to the right. To produce the prints the images had to be reversed in the CAV trays from that previously described. The image is extremely dark but does provide an excellent mapping base as corrections and additions may be made without the need of CAV.

print of a 1:500,000 July 7, 1978, Landsat image, produced at UBC by the author in 1978, was found to cover the study area. This image was produced from EROS Data Center imagery. (The image was located in the authors files after the mapping had been completed on the CAV and cibachrome prints. Before this image was located the author considered reordering and remapping imagery produced at 2xLUT values. The class-

ification and mapping accuracies were greatly improved using the 1978 image as the "ground truth" for the project). While units were too small too to map at 1:500,000, the image colours were clear and sharp. The image was used to verify and correct units mapped from the dark 1980 imagery. The final classification was developed using both images and the CAV data.

Map Drafting

The final boundaries were drafted from the transparent cibachrome print overlays to a sheet of .003mm Draftar mylar. A contact paper print was made from the mylar. Area measurements were made on the paper print. Each unit was traced consecutively three to five times, depending on unit size, with the planimeter. The average area reading, in square inches, taken for each unit was printed within the unit on the paper map. The 1978 and 1980 Landsat cibachrome images were used to correct boundaries or add new units to the mylar base at the time of area measurement.

The final classification was developed after the area measurements had been made. A second check of boundaries and units was made as the classification labels were drafted freehand onto the mylar base. New units missed in the initial mapping and first checking stage were added with subsequent area corrections and additions.

Landsat map scale was determined by measuring the respective distances between three widely spaced Landsat image lakes and their corresponding 1:50,000 topographic map points. The three scale measurements were 1:148,966, 1:148,614 and 1:148,656. The average Landsat map scale calculated was 1:148,755. The planimeter measurements were converted to hectares and the unit areas were drafted onto the final map.

The legend was typed and spliced to the map and a second contact paper print map was made. This map was used to produce the area totals for each class. Each unit was crossed out as the area measurement was tabulated. Map labels missed were found and corrected at this time. The areas for each class were totaled.

RESULTS AND DISCUSSION

Image Quality

Positive transparencies, for CAV use, have been consistantly dark since the author began using the UBC CAV in 1974. This problem was partially solved by ordering density matched images (Murtha and Watson 1975). Subsequently, Canadian Landsat scenes were ordered, begining in 1976, from the EROS Data Center, Sioux Falls, South Dakota. The black and white transparencies produced by EROS were substantially lighter than CCRS imagery and highly suitable for CAV use. In

recent years storage facilities at EROS has resulted in the non production of Canadian scenes.

The dark image problem has been experienced by the Alberta Remote Sensing Center (per. comm. Ian Sutherland). The Alberta Center has found that imagery ordered from CCRS processed at Two Times Lookup Table values (2xLUT) produces brighter imagery suitable for use in the CAV. Examples of black and white transparencies and cibachrome colour composites produced from them were viewed by the author. The cibachrome colour results were comparable to or better than cibachrome prints produced from EROS imagery by the author while employed at UBC.

The image darkness problem was discussed with Mr. Don Hanson of the Prince Albert Satellite Station. Mr. Hanson stated that the imagery could be produced at 2xLUT but at a probable additional cost as 2xLUT imagery is not a standard CCRS product at this time. Currently CCRS produces the imagery using a standard set of lookup tables which may be correct according to statistical analysis but for the user community imagery produced in its current dark format cannot be used in Colour Additive Viewers. Imagery produced at 2xLUT would provide imagery suitable for operational mapping projects using CAV systems. Additional cost would be offset by the information gained.

The Classification

Eighteen classes were established for the study area. The classes were derived primarily from image interpretation of the August 7, 1978, 1:500,000 cibachrome Landsat print and the September 9, 1980, CAV maps and cibachrome prints produced form the later.

The aerial photographs were used for two hours to check the initial CAV classes. Only one set of aerial photographs was availiable for three interpreters. The airphoto "ground truth" data was not availiable to the author for the duration of the project and, more critically, during the final map check. Without the aerial photographs planned accuracy analysis for classification, map and area measurements could not be carried out on an analytical basis. Accuracy estimates were done subjectively.

Further, no field work was carried out by the author as this was part of the experimental design of the project. Classes and their descriptions were based solely on image interpretation. For the above reasons the author is not responsible for any errors or omissions which resulted from lack of field data or use of aerial photographs for the duration of the project.

Class Descriptions

Class descriptions are presented in Table 3.

Table 3.

Class		Comments
I	Old Growth (Coniferous)	
	1. Over Mature	This class covered the largest land area and was separated by dark reddish brown image hues.
	2. Mature	This class was slightly lighter in hue than the former. It was suspected that this class covered a much larger area than mapped and would be more accuratly mapped with imagery produced at 2xLUT values.
II	Second Growth (Coniferous)	
	3. Old Second Growth	This class appeared a lighter shade of brownish red when compared to the Mature types. The boundary between classes 3 and 4 was delineated directly from the CAV screen. The boundary was very difficult to map from the 1978 and 1980 cibachrome prints. Airphoto interpretation confirmed an age/height and/or cover difference between classes three and four. Class 3 occured primarily on what appeared to be an old burn in the SE corner of the map sheet.
	4. Recent Second Growth	This class was a lighter shade of brownish red than class 3. This class also appeared to be located on more recent burns than class 3 and on old cut over areas. The vegetation found on these sites

		was older than that found within the Recent Logging Classes. Stand ages could be added with the addition of field data.
III	Second Growth (Deciduous)	
	5. Old Second Growth and/or Mature	Deciduous stands were confirmed on the aerial photographs. Stands appeared bright red on 1978 imagery and CAV screen and dull orange on the 1980 prints. This class was associated with old burns clearcuts, floodplains and as mature stands on wet site areas.
IV	Recent Logging	
	6. Canopy Cover 60-100% (Deciduous)	Deciduous vegetation was interpreted to be the dominant vegetation on these recent clearcuts.
	7. Canopy Cover 60- 100% (Coniferous)	Vegetation appeared to be predominantly coniferous with some deciduous component. The image hues were darker than the bright red hues of class six. The cut blocks were dominated primarily by reddish hues indicative of vegetative cover. Very little or no blue hues were present which indicated bare ground. Classes 6 and 7 were the oldest of the clear cut classes. Vegetation interpretations made for classes 6 through 9 were done from the 1978 imagery.
	8. Canopy Cover 20-59%	These cut blocks displayed mixed hues of reds and blues which represented vegetated and non vegetated surfaces respectively. These cut block appeared to be younger in age than the former two classes. Vegetation components were suspected to be mixed.

9.	Canopy Cover 0-19% (Non vegetated)	These cut blocks appeared blue on the 1978 image. Red vegetation hues were lacking or occured as a minor component within the unit.
10.	Canopy Cover 0% (1978 - 1980 cutting- non vegetated)	These clearcuts were established after August 7, 1978. They appeared bluish on the 1980 imagery and were not present on the 1978 image. This class was included to illustrate the simplicity of updating landuse changes using Landsat imagery and existing base maps.
10A	Canopy Cover 0% (1978 clear cuts - non vegetated)	These were some of the clearcuts established during and up to August 7, 1978. These cut blocks appeared yellow on the 1978 image. The yellow colour resulted from cut, dead, red brown coniferous foliage which appeared yellow when displayed in the colour infrared mode. The trees had been felled and probably bucked. Slash burning had not taken place.

V Other Classes

11	Burned Areas	These areas were interpreted on the 1978 imagery and were identfied by their fingered boundary characteristics.
12.	Lakes	Lakes appeared black on the imagery. Due to image darkness not all lakes were mapped because of low spectral signature differences between land and water.
13.	Rivers	The Salmon River was the only river wide enough to be mapped from the imagery.
14.	Tidal Flats	Two tidal flat areas were identified. They appeared dark bluish on both images.

15.	Subalpine & Alpine	This class was recognized by dark bluish hues. Rock was the dominant component. Dark brownish hues present indicated some stunted forest stands were also present.
16.	Avalanche Tracks	Avalanche tracks were identified by their bright red deciduous hues. They occured in asscoiation with class fifteen.
17.	Snow & Ice	Snow and Ice units were identified by their white hues.
18.	Rock Slide	One rock slide was mapped. It appeared darker blue than surrounding clearcuts and its apex occured at the top of a mountain.

The other classes not mapped and listed in Table 2 were too small to map. Logging roads were discernable on the 1978 imagery and were often mapped in association with the Recent Logging classes.

Wet meadows could not be seen due to small size and image darkness. However these units could be mapped from lighter imagery. Islands of trees within clearcuts were mapped, usually as class 1. The River class includes its associated floodplain. Agricultural areas were not discernable and were included in the deciduous class.

Hydro lines were not noted on the imagery. Damns and reservoirs were not identified nor were small towns located within the study area. Air strips were too small to delineate.

Area Determinations

Area measurements were calculated for each unit and were placed on the map. It was speculated that area measurements placed on the map would be of value to the resource manager. A summary of areas by class and the number of polygons or units within each class were tabulated (Table 4).

Table 4. Area totals by class.

Class	Total Area (Hectares)	Number of Polygons per class
1	201,965.6	40
2	13,458.9	5
3	15,252.9	2
4	22,404.6	9
5	2,157.4	13
6	1,743.1	12
7	20,222.0	66
8	9,390.0	51
9	7,933.4	107
10	3,352.6	55
10A	1,145.4	14
11	1,897.6	7
11(7)	1,699.1	1
11(8)	4,268.2	4
12	5,483.8	74
13	599.7	2
14	142.8	2
15	5,325.0	31
16	556.5	13
17	204.0	22
18	17.1	1
4/5	8,007.5	4
5//4	5,658.6	1
6/7	4,315.0	1
Totals	337,201.7	537

ACCURACY

Area Accuracy

A major weakness in using a planimeter for measuring areas is that it was slow. However, areas were determined for each class and were presented on the map and the area accuracies were high.

A check of area accuracy was made by measuring the areas of four lakes, of different sizes, on the NTS 1:50,000 maps and comparing the results with those obatined from the Landsat imagery. Assuming the topographic map areas to be correct the Landsat map areas ranged from a low of 92.4% to a high of 105.7%. Area accuracy was determined to be plus or minus 10% and may be as good as plus or minus 5% for more precisely mapped classes. Lake boundaries were difficult to map due to image darkness. Boundary delineation for most classes was judged to be more accurate than those of lakes.

Other classes, such as clearcuts, could not be checked without the black and white photographs. A statistical test could be done by transfering different classes from the photographs to 1:50,000 NTS maps using a transfer scope.

Area accuracy would be higher if the Landsat map units were transfered to a 1:125,000 topographic map base because a known scale would be used to calculate the areas. The CAV image scale, 1:148,755, was based on an average of measurements between lakes. The map scale plus or minus factor

was not known but would be removed by transfer to a topographic base of known scale. Area measurements would be made from the topographic map and area accuracies would be predictably higher.

Boundary Line Accuracy

The high area accuracy implies that boundary placement accuracy was also high. However, with the dark image some classes, otherwise easily delineated, were difficult to discern. Boundary line accuracy was determined for each class. These estimates were based on subjective estimates established during the mapping phase (Table 5). With the aerial photographs a more quantitative estimate would have been determined.

Table 5. Predicted boundary accuracy by mapping class
Legend: Very High - 96-100% correct placement
High - 90-95% correct placement
Moderate - 80-89% correct placement
Low - 70-79% correct placement

Class		Location Accuracy	Comments
1.	Over Mature	High	Good contrast between most other classes
2.	Mature	Moderate	Difficult to separate Classes 1 and 2 if they were adjoining. Easier to discern if boundary was in contact with other classes.
3.	Old Second Growth (Coniferous)	Moderate	Was fairly easy to discern boundary between Mature and Recent Logging

			classes but difficult separate between Recent Second Growth.
4.	Recent Second Growth (Coniferous)	Moderate	Difficult to establish boundary between old second growth classes.
5.	Old Second Growth (Deciduous)	High	Easy to map due to bright red image colour. Some units too small to map.
6.	Canopy Cover 60-100% (Deciduous)	Very High	Sharp cut block boundaries easy to delineate.
7.	Canopy Cover 60-100% (Coniferous)	Very High	Sharp cut block boundaries easy to delineate.
8.	Canopy Cover 20-59%	Very High	Sharp cut block boundaries easy to delineate.
9.	Canopy Cover 0-19%	Very High	Sharp cut block boundaries easy to delineate.
10.	Canopy Cover 0% (1978 - 1980 Cutting)	Very High	Sharp cut block boundaries easy to delineate.
10A.	Canopy Cover 0% (1978 Cutting)	Very High	Sharp cut block boundaries easy to delineate.
11.	Burned Areas	High	Boundries sharp with respect to other classes.
12.	Lakes	Moderate to Low	Dark imagery was cause of low accuracy.
13.	Rivers	High	Good contrast between river and surrounding vegetation.
14.	Tidal Flats	High	Good colour contrast.
15.	Subalpine Alpine	Low	Caused by dark imagery. Boundaries not clear.

16.	Avalanche Tracks	High	Small ones not mappable.
17.	Snow and Ice	Very High	Boundaries very sharp.
18.	Rock Slide	Very High	Boundary very sharp

Classification Fidelity and Homogeneity

Fidelity was defined as adherence to fact or detail, accuracy and exactness (Table 6). The dark image quality was responsible for low classification accuracies for some classes. The accuracies would improve with 2xLUT images. Homogeneity was defined as all parts of the same kind or nature or essentially alike (Table 6). Homgeneity was considered high. Heterogeneous units, 4/5, were included bacause too much mixed detail was present to map as separate units. However, these composite units were homogeneous within their boundaries and with respect to units of the same class. Every effort was taken to map the study area into discreet homogeneous units.

Table 6. Classification fidelity and homogeneity.
Legend: Very High - 96-100%
High - 90-95%
Moderate - 75-89%
Low - 50-74%

Class		Fidelity	Homogeneity
1.	Over Mature	High to Very High	Very High

Class		Fidelity	Homogeneity
2.	Mature	Moderate	High to Very High
3.	Old Second Growth (Coniferous)	Moderate	Moderate to High
4.	Recent Second Growth (Coniferous)	Moderate	Moderate to High
5.	Old Second Grcwth (Deciduous)	High	Very High
6.	Canopy Cover 60-100% (Deciduous)	High	Very High
7.	Canopy Cover 60-100% (Coniferous)	Very High	Very High
8.	Canopy Cover 20-59%	High	High
9.	Canopy Cover 0-19%	Very High	Very High
10.	Canopy Cover 0% (1978 - 1980 Cutting)	Very High	Very High
10A.	Canopy Cover 0% (1978 Cutting)	Moderate May not include all 1978 cutting	Very High
11.	Burned Areas	Low to Moderate	Moderate
12.	Lakes	Low	High
13.	Rivers	High	Moderate to High
14.	Tidal Flats	Very High	Very High
15.	Subalpine and Alpine	Low	Moderate
16.	Avalanche Tracks	High	High

17.	Snow and Ice	Very High	Very High
18.	Rock Slide	high	High

Precision

Precision was defined as the repeatability of a value for each sample (Table 7). The precision of the classification was considered to be high when the 1978 Landsat image was employed in the mapping and classification phases. The methodology using the CAV alone with the dark imagery was considered low to moderate. The precision would improve to high with 2xLUT imagery. The production of the cibachrome prints from the 1980 imagery increased the mapping and classification precision. The cibachrome print provided a hard, contact, copy of the CAV display which was used to make map corrections. The prints were considered to be an invaluable part of the project since only limited amount of time was availiable to be spent on the CAV.

The classification used for this study was similar to that developed by Murtha and Watson (1975)(Appendix A). This suggests that mapping of Vancouver Island using the same classification could be carried out. The precision of the methodology and especially the classification would have been increased with addition of field work and use of the black and white photographs for the duration of the study.

Table 7. Repeatability of a value for each sample unit.
Legend: Very High - 96-100%
High - 90-95%
Moderate - 80-89%
Low - 70-79%

Class		Repeatablility or Precision
1.	Over Mature	High to Very High
2.	Mature	Moderate
3.	Old Second Growth (Coniferous)	High
4.	Recent Second Growth (Coniferous)	Moderate
5.	Old Second Growth (Deciduous)	High
6.	Canopy Cover 60-100% (Deciduous)	High
7.	Canopy Cover 60-100% (Coniferous)	Very High
8.	Canopy Cover 20-59%	High
9.	Canopy Cover 0-19%	Very High
10.	Canopy Cover 0% 1978-1980 Cuttings	Very High
10A.	Canopy Cover 0% 1878 cuttings	High
11.	Burned Areas	Moderate
12.	Lakes	Moderate to Low
13.	Rivers	High
14.	Tidal Flats	High
15.	Subalpine and Alpine	Moderate
16.	Avalanche Tracks	High
17.	Snow and Ice	Very High
18.	Rock Slides	High

Times Required for Each Phase

The times required for each phase of the project were recorded (Table 8).

Table 8. Break down of time spent on the project.

Phase	Time Spent in 8hr. Mandays
Mapping Landsat imagery on CAV including Travel time to Edmonton	3.63
Mapping final copy including map corrections and development of the classification	2.84
Measuring Areas in square inches. Did not include conversion to hectares	2.78
Hand drafting of map, conversion of areas to hectares and typing of the legend and totaling of the areas	3.28
Writing and typing of the report	3.31
Total	15.84

It was concluded that four 1:50,000 map sheet areas, depending on complexity, could be mapped to the level of accuracy and detail achieved on the enclosed Landsat map (Appendix B) in 16 to 18 man days and that with 2xLUT imagery the mapping time could be reduced and the accuracy increased.

SUMMARY and RECOMMENDATIONS

Methodology

Imagery should be ordered at 2xLUT. The Canada Centre for Remote Sensing should be made more aware of the imagery problem encountered when attempting to use standard product black and white transparencies on Colour Additive Viewers. It is recommended that a copy of this report be sent to CCRS and to the Alberta Remote Sensing Center.

The use of Colour Additive Viewers for this type of work is recommended because of the enhancement abilities. Subtle differences between units were not always visible on the cibachrome prints.

Cibachrome prints formed an invaluable part in the completion of the project. They shoud be used as part of any future mapping projects of this nature.

Landsat mapping should be transfered to 1:125,000 topographic maps if they are availiable. Area measurements should be made from the topographic maps. Increased area accuracy would be obtained.

The use of a planimeter, while taking 2.78 days to measure all areas, allowed area measurements to be placed on the map.

The 1978 Landsat image was used as the ground truth for this study as the aerial photographs were availiable on a limited basis. The photographs must be availiable for the duration of the study to check the classification accuracy.

It was concluded that 2xLUT imagery used in conjunction with a Colour Additive Viewer, the production of cibachrome prints for map correction purposes and the used of conventional black and white aerial photographs coupled with some field work would provide an accurate and inexpensive method of mapping and classifying large areas on Vancouver Island. It was also concluded that mapping and classification accuracy was about 85%.

ACKNOWLEGEMENTS

The author expresses sincere thanks to Cal Briker, Alberta Remote Sensing Center, for the use of the Center's facilities, to Ian Sutherland for his assistance in producing the experimental cibachrome prints and to Ken Cambell for his time and assisitance.

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APPENDIX A

Mapping Classification Developed by Murtha and Watson (1975).

I Old Growth

1. Over Mature

2. Mature

II Second Growth

3. Old Second Growth

4. Recent Second Growth

III Recent Logging

5. Canopy cover 75-100%

6. Canopy cover 50-74%

7. Canopy cover 10-49%

8. Canopy cover less than 10%

1973 clearcutting

1974 clearcutting

APPENDIX B

REPORT OF JOHN BUNNING

(Note: Reproduced as submitted to Talisman for comparison analysis)

LANDSAT

PAPER PRINT ANALYSIS FOR WILDLIFE HABITAT MAPPING

for

RESEARCH BRANCH

B.C. MINISTRY OF FORESTS

VICTORIA, B.C.

prepared by

John Bunning

December 1981

Project 81-068

TALISMAN
Land Resource
Consultants
300-842 Thurlow St.
VANCOUVER B.C.
V6E 1W2

OUR FILE: 81-068

December 14, 1981

Ms. K.L. Sadoway
Research Branch
B.C. Ministry of Forests
31 Bastion Square
Victoria, B.C.
V8W 3R7

Dear Ms. Sadoway:

Following is my report on the paper print analysis for mapping wildlife habitat types in the Sayward area of Vancouver Island. The 1:125,000 scale map has already been sent to you.

I trust that the map and report will meet your needs. If you have any questions please feel free to contact me or Mr. Wayne Biggs at our Victoria office (phone: 388-5467).

Yours truly,

John Bunning
TALISMAN LAND RESOURCE CONSULTANTS

JB:kr

Enclosure

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CHAPTER 1

INTRODUCTION

Talisman Land Resource Consultants was retained in November, 1981 to undertake the paper print analysis of Landsat Imagery for the Sayward area on Vancouver Island for the Research Branch, B.C. Ministry of Forests. The analysis is part of a larger study comparing three different methods of interpreting Landsat imagery for mapping wildlife habitats and is part of the B.C. Ministry of Forests' Integrated Wildlife-Intensive Forestry Research (IWIFR) program.

Based on the paper print analysis of Bands 4, 5 and 7 Landsat imagery, a wildlife habitat map at a scale of approximately 1:125,000 has been produced. Interpretation was conducted using visual analysis. Colour separation was aided by using Munsell colour chips. At finer levels of detail, ranges of colour chroma and value within a hue were correlated to habitat types by reference to relatively large scale (1:20,000, 1:40,000 and 1:50,000) black and white aerial photographs.

The project, including map and report production, was conducted by John Bunning, C.E.T. Mr. Bunning is a forest technologist on the staff of Talisman Land Resource Consultants. He has extensive experience in the interpretation of aerial photography and other remote sensing imagery for soil, vegetation, wildlife habitat and land use mapping.

Twenty-five map units including six landscape units, eleven pure habitat type units and eight complex units (referred to as "habitat combinations") were identified and mapped. The map units are listed and described in Table 1. The estimated areas of each map unit are summarized in Table 2.

CHAPTER 2

METHODS

The approach used to interpret the wildlife habitat map units is shown schematically in Figure 1. Units were systematically identified and subdivided at four levels of recognition.

INTERPRETATION OF MAP UNITS

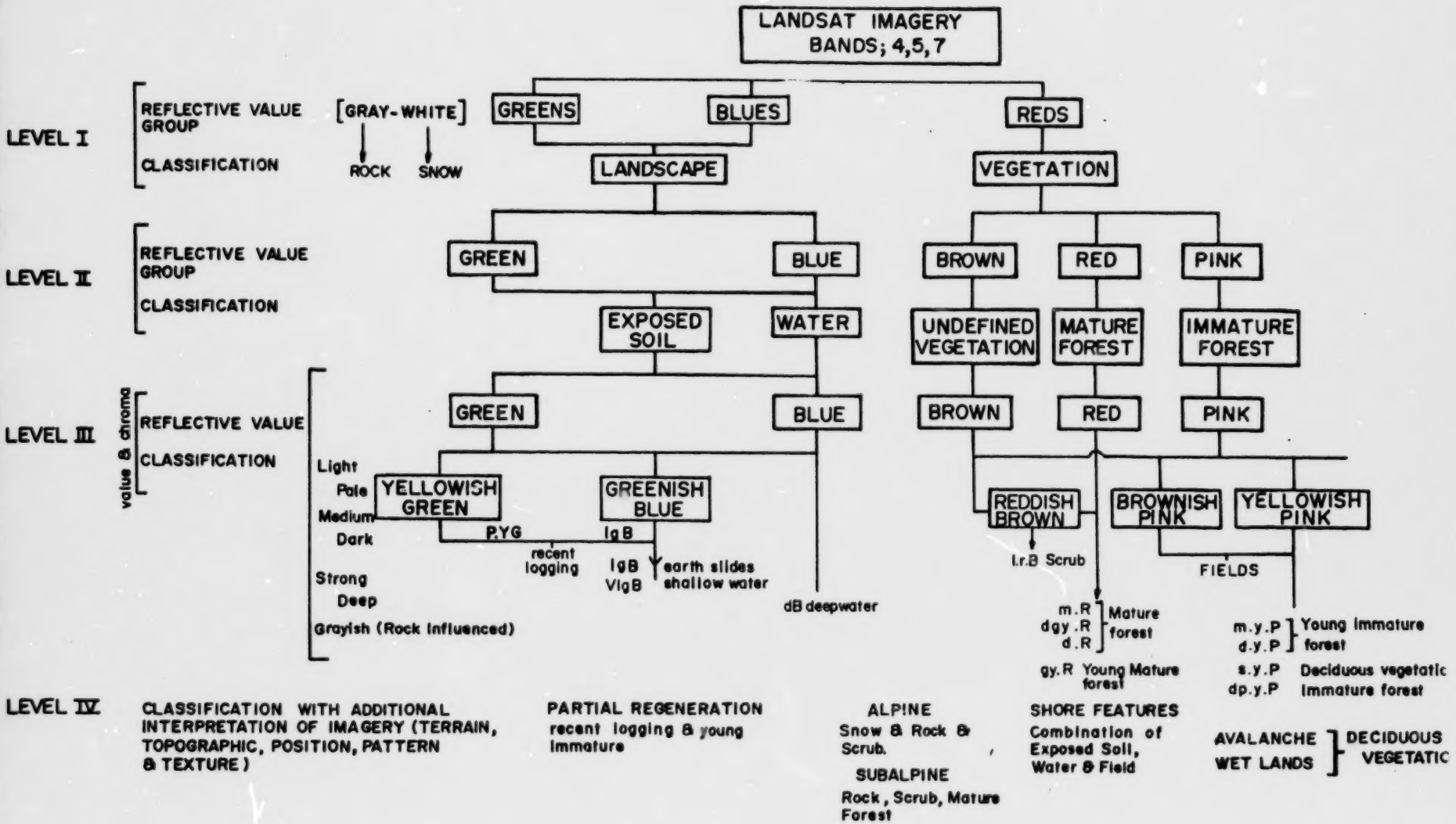
At Level I, obvious differences between strongly contrasting colour* hues were separated into different units. White and gray colours correspond to snow and rock, respectively. Blue (band 4) and green (band 5) correspond to sparsely vegetated or bare soil and to water. Red (band 7) corresponds to vegetation.

At Level II, greens and blues are separated into soil and water, respectively. Reds are subdivided as follows:

---

* "Reflective value" is a technically more correct term. For simplicity, "colour" will be used in the text of the report.

FIGURE I


LANDSAT IMAGERY BANDS; 4,5,7
LEVEL I
REFLECTIVE VALUE GROUP
CLASSIFICATION
[GRAY-WHITE]
ROCK
SNOW
GREENS
BLUES
REDS
LANDSCAPE
VEGETATION
LEVEL II
REFLECTIVE VALUE GROUP
CLASSIFICATION
GREEN
BLUE
BROWN
RED
PINK
EXPOSED SOIL
WATER
UNDEFINED VEGETATION
MATURE FOREST
IMMATURE FOREST
LEVEL III
value & chroma
REFLECTIVE VALUE
CLASSIFICATION
GREEN
BLUE
BROWN
RED
PINK
Light
Pale
Medium
Dark
Strong
Deep
Grayish (Rock Influenced)
YELLOWISH GREEN
GREENISH BLUE
REDDISH BROWN
BROWNISH PINK
YELLOWISH PINK
P.YG
recent logging
lgB
lgB
VlgB
earth slides
shallow water
dB deepwater
l.r.B Scrub
FIELDS
m.R
dgy.R
d.R
Mature forest
gy.R Young Mature forest
m.y.P
d.y.P
Young immature forest
s.y.P
dp.y.P
Deciduous vegetatic
Immature forest
LEVEL IV
CLASSIFICATION WITH ADDITIONAL INTERPRETATION OF IMAGERY (TERRAIN, TOPOGRAPHIC, POSITION, PATTERN & TEXTURE)
PARTIAL REGENERATION
recent logging & young immature
ALPINE
Snow & Rock & Scrub.
SUBALPINE
Rock, Scrub, Mature Forest
SHORE FEATURES
Combination of Exposed Soil, Water & Field
AVALANCHE
WET LANDS
DECIDUOUS VEGETATIC

* pink - immature forest
* red - mature forest
* brown- not differentiated at this level

Identification of preliminary map units at Levels I and II is accomplished quite simply and rapidly.

Level III is more demanding. At this level, units defined as Level II are subdivided according to the range of colour values and chromas within a colour hue. Accordingly, a number of apparently different groups are defined. These groups are then "calibrated" by reference to large scale black and white aerial photographs. The photographs were, in effect, updated by reference to recent forest cover and history maps where required. Based on the calibration, final groups were defined and limits were established according to ranges of colour.

A set of centroid colour charts published by the Inter-Society Colour Council and the National Bureau of Standards (ISCC-NBS) were used as an aid in defining colours. Each chart consists of a series of colour chips defined on the Munsell scale of hue (primary colour), value (lightness) and chroma (departure from neutral). The ISCC-NBS system is specifically designed to define colours most commonly found in colour photographic imagery. The descriptive titles for specific numerical colour notations associated with various map units are listed in the right-hand column of the map legend (also see Table 1).

Black and white vertical aerial photographs were viewed stereoscopically with a fixed-mirror magnifying stereoscope to calibrate Level III map units. Interpretation was aided further by reference to forest inventory maps to determine stand ages where necessary.

Definition of map units at Level IV represents a departure from the systematic approach. Level IV mapping relies mainly on the interpretive skill and judgement of the analyst. Areas obscured by cloud or shadows and complex map units are identified at this level.

For areas obscured by cloud or shadow the analyst must rely on reference checks to aerial photography and unit boundaries must be approximated based on the surrounding visible units and existing nearby patterns of units.

Complex map units (including the "habitat combinations") were defined in two cases:

* where two distinct types could be identified from the imagery but were too small to be mapped at the 1:125,000 scale

* where two or more distinct colours occurred in a unique texture or pattern and individual types could not be interpreted from the imagery

Examples of the first case are the mature coniferous forest with scrub ($M_2/\bar{x}$) and the mature coniferous forest with bedrock occurring near the soil surface ($\frac{M2}{R}$). Examples of the second case are the mixtures of immature coniferous forest with deciduous vegetation (I_2, D; I_2/D; D/I_2); mixtures of young mature and mature coniferous forest (M_1, M_2); mixtures of young mature coniferous forest with immature coniferous forest (M_1, M_2); and mixtures of young mature coniferous forest with deciduous vegetation (M_1/D).

The subalpine type (SA), although defined as a pure map unit (see Table 1), is really a complex of mature forest, scrub and

rock. Therefore, discussion of mapping this type corresponds to Level IV (see Figure 1).

TECHNICAL PROCEDURES

A preliminary working map of the study area was drawn on a 5 mil sheet of clear acetate registered to the Landsat imagery with a seven-point registration bar. Boundary lines were drawn with Staedler Lumocolour fibre-point pens with a 0.3mm tip which produced a line about 0.5mm wide.

On completion of the working map, the area of each map unit was calculated using a Talis-SMART digitizing table coupled to a microcomputer. Because of the brittle nature of the acetate and the impermanence of the ink, the map was retraced on opaque mylar using a 0.5mm-tip pen.

The work space consisted of a glass surfaced drafting table with an internal light source. Overhead lighting was from a fixed fluorescent ceiling fixture and was used for most of the mapping since natural light during November (when the mapping was done) is too variable. However, the comparison of imagery colours to the colour chips was done in natural light.

A summary of materials and equipment required for the analysis follows:

Materials

Landsat imagery, bands 4, 5 & 7 at 1:125,000 scale
acetate sheet (107 x 76cm)
mylar sheet (107 x 76cm)
registration bar
lumocolour pens (for acetate)

Equipment

internally lit drafting table

mirror stereoscope

Talis-SMART digitizing table and computer (a planimeter could be substituted)

ISCC-NBS centroid colour system charts (published by the American Society of Photogrammetry)

Reference Materials

black and white vertical aerial photographs

forest cover maps

CHAPTER 3

RESULTS

A mylar overlay of the Landsat imagery with a legend describing 25 map units at an approximate scale of 1:125,000 was produced. The map legend is reproduced in Table 1. A summary of the areas of each map unit, the total map area and the percentage of each map unit relative to the total map area is presented in Table 2.

CHAPTER 4

TIME AND COSTS

Production of the habitat type map required a total of 47.1 hours or 6.3 days based on a seven and one-half hour workday. A summary of the time, materials and costs follows. Labour costs are based on a $30.00/hr rate.

Preparation		
Planning methodology and review of literature	3.0 hrs.	$ 90.00
Arrange work space, assemble equipment and materials; register acetate to imagery	2.0 hrs.	$ 60.00
Mapping interpretation	16.35 hrs.	$490.50
Legend development	3.25 hrs.	97.50
Area compilation: digitizing	10.5 hrs.	315.00
summary	3.0 hrs.	90.00
Final Map Production		
Redraft and label map units	8.0 hrs.	240.00
Final check	1.0 hrs.	30.00
	47.1 hrs.	$1,413.00

Miscellaneous Expenses	
Mylar sheet	$ 3.60
Acetate sheet	1.80
Miscellaneous materials	13.48
Rental - digitizing equipment (10½ hrs. @ $25)	262.50
Total Expenses	$ 281.38
TOTAL COST	$1,694.38

It should be noted that the total cost ($1,694.38) does not include report production costs which Talisman has charged to the project. The purpose of this time and cost figures presented in this report are to provide a basis for comparison with other mapping techniques. Report writing and evaluation of accuracy, precision, etc. are not considered to be relevant to this purpose.

CHAPTER 5

DISCUSSION

The systematic approach using standard reference colours (ISCC-NBS) increases the objectivity and repeatability of an inherently subjective exercise. However, adherence to the systematic approach also increases the time required for interpretation. Standard colours do not always exactly match colours on the Landsat imagery. Therefore, considerable care must be taken. As work proceeds, familiarity is gained with the range of colours on the Landsat image and mapping becomes somewhat easier and more rapid.

It is emphasized that black and white aerial photographs were used for calibrating units which were discernable from the Landsat imagery. The only exception was in a very few cases where clouds or shadows obscured the imagery.

Calibration of map units at Level III must consider the variability in colour associated with differences in soil moisture,

aspect and phenology of the vegetation throughout the map area. Therefore, careful selection of areas used for calibration is required. Some map units do not have a strong contrast in colour; this is the case for many map units defined at Level IV. In such cases, imagery pattern and texture or topography and landforms were used to aid in identification.

ANALYSIS OF ACCURACY

Determination of the level of accuracy of the mapping require comparison against some known standard such as some other detailed ground-truthed map. Lacking this standard, only some subjective judgement based on some checking of reference photos and maps can be made. The judgement is that the level of accuracy is high, probably about 90 percent. In an attempt to give a more objective assessment of accuracy, fifty points were randomly selected throughout the map area and checked against reference material. Of these fifty points, forty-three were absolutely correct. Of the seven incorrect points, at least some might be explained as representing inclusions within a map polygon. This check suggests an accuracy of at least 86 percent. Because of the relatively small sample size and the small proportion of the total area of many of the map units, this test cannot be considered rigorous.

Another approach to assess accuracy more objectively is to use the same fifty sample points as a basis for an independent estimate of map unit areas. This test indicated that the proportion of areas of map units shown in Table 2 is within 95 and 99 percent confidence limits with two exceptions: young mature coniferous forest (M_1) and the mature coniferous forest with scrub ($M_2/\bar{x}$) units. Both of these units appear to be underestimated. It must be noted that this text is not rigorous because

of the relatively small number of samples and the relatively large number of types which represent only a small proportion of the total area.

ANALYSIS OF PRECISION

Precision can be defined in two ways, referring either to the fineness of measurements and calculations or to the repeatability of the mapping. Precision in the first sense is difficult to evaluate without some existing standard. Precision, in this sense, is affected by map scale, scale distortion in the Landsat imagery and by the degree of colour contrast between adjacent map units. The effect of scale distortion in the imagery is difficult to evaluate without further knowledge. It will effect the placement of boundary lines and, therefore, estimated areas.

Even where boundaries appear abrupt because of strongly contrasting colours, boundary locations could be out of place by as much as about 140m due to the combined effects of pixel size and type line widths. Theoretically, this could result in an error of more than 40% for a circle with an actual area of 1 square centimetre on the map (about 156 ha on the ground). This percent error decreases as polygon size increases; for a circle about 12.5 square centimetres in area (radius of about 2cm, representing an area of almost 2000 ha) the error is about 12%. The error also decreases considerably for non-circular polygons. The maximum error for a square 1cm x 1cm (156 ha) is about 24%; for a 2cm square (625 ha), about 11%. Because map units are irregularly shaped and if error in boundary placement is more or less random, the precision of map unit area estimates should be within $\pm$ 15%.

Error associated with digitizing map units can be regarded as negligible. With the Talis-SMART electronic digitizing equipment, areas can be measured to about the nearest $0.25mm^2$, representing an area of about 0.4 ha at the 1:125,000 map scale. This is slightly less than the area represented by one pixel, 0.44 ha.

The total area determined from the habitat type map was compared to the total area determined from NTS topographic maps. The areas were 322,430 ha and 332, 850 ha respectively. This difference of 10,420 ha suggests that the error in area determination is about 3% (low). This can be taken as a rough estimate of the level of precision associated with scale distortion in the imagery and the limitations of the digitizing equipment and procedures.

Precision in the second sense, i.e., repeatability is inherently rather low for visual analysis. Use of a systematic appraoch with standard ISCC-NBS colour reference charts results in relatively high degree of repeatability.

HOMOGENEITY OF MAP UNITS

It is difficult to give a precise indication of the homogeneity of map units. Because of the manner in which map units are defined (many complex units), inclusions are not expected to amount to more than about 10%.

CHAPTER 6

SUMMARY AND CONCLUSIONS

A 1:125,000 habitat type map showing 25 map units was produced through visual analysis for the Sayward area on Vancouver Island. The map legend, including type descriptions, is shown in Table 1. A summary of map unit areas is shown in Table 2.

A systematic approach, as indicated in Figure 1, was used. This approach, using standard ISCC-NBS reference colours, should result in a high degree of repeatability. Accuracy of the mapping is expected to be high; probably in the neighborhood of 85% to 90%. Precision in the location of map boundaries and estimation of areas is estimated to be approximately 80% or more. Precision, in terms of repeatability, is high, as mentioned above. The degree of homogeneity of map units is also estimated to be high, probably about 90%. It must be noted, however, that estimates of accuracy, precision of unit boundaries and area calculations and homogeneity are difficult to assess since there is no standard, such as ground truthing or a detailed map, for reference.

The total time required for the mapping was 47.1 hours. At $30/hour, this corresponds to a labour cost of $1,413.00. The total cost of map production was $1,694.38. This amounts to a cost of about one-half a cent per hectare.

APPENDIX A

TABLE 1

LEGEND

LANDSAT IMAGE ANALYSIS; SAYWARD WILDLIFE HABITAT

MAPPING UNIT	UNIT SYMBOL	UNIT DESCRIPTION	LANDSAT IMAGERY CHARACTERISTICS*
			*ISCC - NBS centroid colour system
LANDSCAPE UNITS			
Deep water bodies	L	deep inland water bodies; lakes	dark Blue
Shallow water bodies	SW	shallow inland water bodies; wide river beds	very light greenish Blue
Shore features	S	tidal flats, beaches, estuaries	dark grayish Red and light greenish Blue
Snow	*		White
Alpine		rock, alpine vegetation; scattered trees in association with snow and subalpine map units	light grayish Brown, light reddish Brown, medium Gray
Avalanche tracks		shrub growth on avalanche tracks cutting through surrounding forest vegetation	strong yellowish Pink
Land slides		recent massive earth movements which have not revegetated	light greenish Blue
Rock	R	exposed rock surface other than alpine	medium Gray
HABITAT UNITS			
Clear cut and recently logged		no indication of regeneration, may have significant areas of exposed soil	light grayish Green
Partial Regeneration	PR	complex of coniferous and deciduous regeneration with areas of exposed soil or very sparse regeneration	complex pattern of light grayish Green and dark yellowish Pink
Young Immature	I_1	regeneration of coniferous and deciduous trees and/or deciduous ground cover, open canopy	medium yellowish Pink to dark yellowish Pink
Immature	I_2	well established coniferous regeneration, some minor inclusions of deciduous trees, closed canopy	near deep yellowish Pink

LANDSAT IMAGE ANALYSIS; SAYWARD WILDLIFE HABITAT LEGEND (Continued)

MAPPING UNIT	UNIT SYMBOL	UNIT DESCRIPTION	LANDSAT IMAGERY CHARACTERISTICS*
HABITAT UNITS (Continued)			
Young mature	M_1	closed canopy, coniferous forest, aged 40 to 80 years	grayish Red; light grayish Red with bedrock near surface
Mature	M_2	closed canopy, coniferous forest, aged 80^+ years	range of colours (influenced by shadow) dark grayish Red, dark Red, grayish Red or medium Red
Scrub	X	scattered mature coniferous with dense scrub ground cover	colour pattern produced by combination of grayish Red, light reddish Brown, and grayish Pink
Sub Alpine	SA	predominantly deciduous shrubs with few scattered coniferous trees, and some exposed rock	colour pattern produced by combination of light reddish Brown and gray yellowish Pink
Deciduous	D	dominantly deciduous vegetation	strong yellowish Pink to dark yellowish Pink
Wet lands	w	bogs, fens and marshes	strong yellowish Pink, often associated with open water
Fields	F	cleared land no longer used for forestry purposes	brownish Pink and grayish yellowish Pink
HABITAT COMBINATIONS			
equal proportions	,	equal areas of each type, i.e. I_2, D	individual habitat types, distinguished by colour but pattern of units too small to separate
unequal proportions	/	habitat feature to left of / greater than habitat feature to right, i.e. I_2/D	individual habitat types, distinguished by colour but pattern of units too small to separate
influenced by	-	used with bedrock only; habitat feature above is influenced by bedrock at or near the surface, i.e., $\frac{M_1}{R}$	colour of habitat feature modified by grayish chroma and paler values

TABLE 2

MAPPING UNIT AREA SUMMARY

Mapping Unit	Unit Symbol	Unit Area	% Of Total Map
Landscape Units			
Deep water	L	5820	1.8
Shallow water	SW	227	0.07
Shore features	S	132	0.04
Snow	*	546	0.20
Alpine	A	2771	0.90
Rock	R	632	0.20
Subtotal		10128	3.2
Habitat Units			
Clear cut and recently logged	e	5397	1.7
Partial regeneration	PR	16089	5.0
Young Immature	I_1	27275	8.5
Immature	I_2	8040	2.5
Young Mature	M_1	456	0.14
Mature	M_2	166654	51.8
Scrub	$\bar{x}$	7334	2.3
Subalpine	SA	17880	5.6
Deciduous	D	3470	1.1
Wetlands	W	352	0.1
Fields	F	266	0.08
Habitat Combinations			
Equal areas of each unit	I_2, D	2611	0.8
"	M_1, M_2	1842	0.6
Unit greater than 50% of area to left of /	I_2/D	5502	1.7
"	D/I_2	9032	2.8
"	M_1/I_2	1795	0.6
"	M_1/D	31189	9.9
"	M_2/$\bar{x}$	6379	2.0

Table 2 cont'd.

Mapping Unit	Unit Symbol	Unit Area	% of Total Map
Unit influenced by Rock	$\frac{M_2}{R}$	473	0.2
Subtotal		312036	96.8
TOTAL		322430	100%

APPENDIX C

REPORT OF G. TOMLINS

(Note: Reproduced as submitted to Talisman for comparison analysis)

EVALUATION OF LANDSAT DIGITAL DATA FOR A WILDLIFE HABITAT CLASSIFICATION ON VANCOUVER ISLAND

Project No. 1-13-800

Prepared for:

Research Branch
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November 18, 1981

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EVALUATION OF LANDSAT DIGITAL DATA FOR A WILDLIFE HABITAT CLASSIFICATION ON VANCOUVER ISLAND

1.0 INTRODUCTION

B.C. Research, under contract to the Research Branch, Ministry of Forests, has undertaken an analysis of LANDSAT digital data for the provision of information concerning wildlife habitat in the Sayward forest study area of Vancouver Island. This work was undertaken as part of the Integrated Wildlife Intensive Forestry Research (IWIFR) Program on Vancouver Island, which is a jointly funded, 1.3 million dollar cooperative program between the Ministries of Environment and Forests, industry and public conversation groups (B.C., 1981).

The investigation reported herein is one part of a project whose objective is to evaluate the potential of three different LANDSAT classification methodologies for a wildlife habitat classification (Sadoway, 1980). The report briefly describes the principles of digital classification of LANDSAT data, describes in depth the methodologies employed in this particular study, and presents in full the results of the study.

2.0 Introduction to Methods

2.1 Principles of Digital Analysis

The ground resolution of the LANDSAT multispectral scanner (MSS) data is 79 meters in the across-track direction, and 57 meters in the along-track direction due to overlap of successive scans. Each 185 km x 185 km LANDSAT scene thus contains more than 7.5 million "elements" describing spatial distribution. Each "element", or pixel as they are commonly referred to, is spectrally characterized by the average radiance value (on a scale of 0 to 63) as measured by the sensor in each of four wavelength bands. Each full LANDSAT scene therefore contains approximately 30 million items of data. During ground processing, the raw MSS data are corrected, formatted and converted to a useable binary form on computer compatible tape (CCT). CCT's produced by the Canada Centre for Remote Sensing (CCRS) have a radiometric correction applied to rectify the sensor gain changes, during which stage the spectral radiance values are distributed over a broader scale from 0 to 255 digital numbers (DN) in all four MSS bands (Strome et.al., 1975).

The radiance values received from a target on the ground allow for the interpretation of the nature of the ground cover. A four-dimensional SPECTRAL SIGNATURE may be constructed from a known ground feature, from which other pixels in the LANDSAT data set having similar spectral characteristics are classified. The spectral signature is defined as a quantitative measurement of the properties of an object at one or several wavelength intervals (Reeves et.al., 1975).

Table 1 below illustrates the spectral signatures of three different ground features. The signature in this instance are defined in terms of the mean radiance ($\bar{x}$) and standard deviation (SD). The values given are actual radiance distributions obtained during this investigation.

MSS band, wavelength in microns, and corresponding colour	Typical radiance distribution (0-255 DN) in each MSS band for selected targets.					
	Deep, Clear Water (n=3066)		Coniferous Forest (n=74)		Deciduous Forest (n=81)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
MSS4 (0.5-0.6μ) Green	14.4	1.1	18.8	1.5	22.1	1.6
MSS5 (0.6-0.7μ) Red	7.5	1.1	14.4	1.9	19.6	1.7
MSS6 (0.7-0.3μ) Red/Infrared	2.6	1.1	57.0	11.1	88.1	8.6
MSS7 (0.8-1.1μ) Photographic Infrared	0.1	0.4	63.2	15.6	101.9	9.2

Table 1 Spectral Descrimination between Three Categories of Ground Cover

$\bar{x}$ = mean radiance from n pixels
SD = standard deviation

Near infrared radiation (MSS bands 6 and 7) is characterised by almost total absorption by water, and by strong reflectance from healthy green vegetation. The radiance due to CONIFEROUS FOREST pixels is thus significantly higher in these two bands than from WATER pixels. The greater surface area of broad-leaf vegetation, and the more horizontal orientation of the leaves results in another significant increase in near infrared radiances from DECIDUOUS FOREST pixels. Such differences in radiance observed in one or more of the four LANDSAT spectral bands allows for the definition of spectral signatures for different ground cover types, and are the basis of digital analysis techniques for the LANDSAT data.

2.2 Supervised and Unsupervised Classification Techniques

The basic difference between supervised and unsupervised classification techniques is that in the supervised approach the image analyst decides in advance which strata he desires to

be classified, whilst unsupervised classifications involve algorithms which examine all of the pixels in the data-set and divide them into a number of classes based on the dominant spectral groupings present in the data.

A supervised, signature acquisition technique followed by N-dimensional training and the Maximum Likelihood Decision rule (Economy et.al., 1974) was employed in this investigation. Training sites, representative of specific ground features (such as water, coniferous forest and alpine grasslands) were identified from aerial photographs. Boundaries of each training site were transferred to the LANDSAT imagery and the 4-dimensional spectral signatures acquired. Following an analysis of the signatures, and modifications to the classification system, a final set of spectral signatures constituted the training data-set for the supervised classification.

N-dimensional training examines the 4-dimensional (4-band) distribution of radiances of every pixel in the data-set. Each pixel is then assigned to one or more of the training data-set classes according to its radiance distribution. There will often be overlap between two classes, and a pixel will initially be assigned to both. Following N-D training, the Maximum Likelihood Decision rule (MLDR) is used to examine all instances of overlap, and "decide" upon the "most likely" assignment. This decision is based upon Gaussian probability theory, and is explained in Schlien and Goodenough (1973).

An excellent description of the principles and methods of digital image classification is given in Lillesand and Kiefer (1979).

3.0 The Sayward Forest LANDSAT Study: Description of Methodologies

3.1 Study Area

The study area is SAYWARD FOREST on north eastern Vancouver Island (see Plate 1). The limits of the area correspond to the Vancouver island portion of four 1:50,000 map sheets - 92 K/4, 92 K/5, 92 L/1 and 92 L/8. The total area of terrain classified including Johnstone Strait and the Gulf Islands to the north and east of the study area is some 4200 square kilometers. As software was not available to exclude these islands from classification, classified units lying outside the area were later removed using an electronic digitizer (sectior 3.2.8) The study area was found to encompass 3,481 square kilometers.

3.2 Description of Methods

3.2.1 Data Preprocessing

Digital LANDSAT DICS* data acquired on the 9th September 1980 were analysed in this investigation. These data are resampled to be compatible with 1:50,000 Canadian NTS map-sheets, are oriented in a N-S direction, and have a pixel size representing 50m x 50m on the ground. The DICS data supplied for this study were on two separate tapes due to the impossibility of resampling into one data-set those data which lie on both sides of a 6° latitude boundary (see Moore and Bonnar, 1980). The two DICS scenes were therefore merged into one data-set containing the entire study area.

* DICS - Digital Image Correction System (see Butlin et.al., 1978)

Since software was not previously available for this task, the necessary program was written and loaded onto the M.D.A.* Image Analysis System. It should be noted that different image analysis systems maintain different software configurations. The CCRS image analysis system and the GEMS** system at the Pacific Forest Research Centre for example both have as standard software capable of merging two image scenes.

3.2.2 Initial Training Data Acquisition and Classification System

Digital LANDSAT classification techniques rely primarily on spectral differences (analogous to hue and tonal differences) between ground cover classes in order to categorize each class. The greater the spectral contrast between two features, the better the classification accuracy. A list of sixteen potentially discriminable land-cover classes with relevance to wildlife habitat classifications was prepared by B.C. Research following discussions with representatives of the Integrated Wildlife Intensive Forest Research (IWIFR) program. Table 2 lists the original classes identified for subsequent analysis and the individuals who compiled this list are identified in Appendix 1.

As desired classes were specified in advance of the computer classification, a supervised approach was adopted in this investigation (section 2.2). The IWIFR representatives identified training sites for each class from which the LANDSAT data was classified. Sixty-seven polygons were identified from black-and-white airphotos at nominal scales varying from 1:20,000 to 1:50,000 Appendix 2 lists details of this imagery. Twenty of these polygons could not be reliably

* MDA - MacDonald, Dettwiler and Associates

** GEMS - Geographic Monitoring System

located on the LANDSAT imagery, and were thus excluded from the training data-set. The remaining 47 polygons comprised the source data for "training" (i.e. acquisition of spectral signature for each class).

At least one training site was acquired from the air-photos for each of the sixteen original classes. Where possible, three or more training sites were established geographically separated from each other, eg. one site in each of the four N.T.S. map sheets comprising the study area. For those classes with low frequency of occurrence, or for which sufficient large, homogeneous stands could not be readily identified from the air-photos, training statistics were acquired from photographs in only one or two of the NTS map sheet areas.

3.2.3 Refinement of the Classification System

During the analysis it became apparent that certain of the original classes needed to be described in more specific levels of generalization that was originally requested by the IWIFR. Two clear-cut classes (non-vegetated and regenerating) were originally scheduled for classification. However, when enhanced LANDSAT imagery was viewed on the M.D.A. T.V. monitor, three classes of clear cut were discriminable. Since these three classes were spectrally very different they were classified separately in order to minimize the overlap between spectral signatures, which effect would tend to reduce classification accuracies. For the same reason, the initial "undifferentiated rock" class was divided into three new classes representing different rock environments (non-vegetated, vegetated, ice or snow

covered). A "shadow" class was also included in the classification scheme in an attempt to discriminate shadowed portions of the scene from water. Table 3 describes the distinguishing features of these classes.

Some reduction of the classification scheme also took place following analysis of the spectral signatures acquired from each training site. This is discussed in Section 3.2.6. The overall development of the classification system is given in Table 4.

3.2.4 Spectral Signature Acquisition

The locations of the training sites derived from the aerial photography were compared with an enhanced colour image displayed on the T.V. monitor. As stated in Section 3.2.2, 47 of the original 67 training sites could be reliably identified on the LANDSAT image. A cursor was used to draw polygons on the T.V. screen, the areas of which represented each of the training site classes. The coordinates defined by each of the polygons allowed for sampling of the LANDSAT data to acquire spectral signatures for each training site. The spectral signature is defined by the mean intensity and standard deviation of the sample in each of the four LANDSAT Multispectral scanner (MSS) bands. The sample (n) is the number of pixels (50m x 50m data elements) in each training site. Spectral signatures were also similarly acquired for the four extra classes discussed in the previous section. A total of 51 spectral signatures, representing 20 classes were thus obtained. Table 5 lists the mean intensities ($\bar{x}$), the standard deviations (SD) and number of samples (n) for each training site. Also included is the composite training

signature used in subsequent analysis. The composite value is the weighted mean and standard deviation derived from the individual spectral signatures in each class.

3.2.5 Composite Spectral Signature Generation

An analysis of each of the spectral signatures was undertaken to determine the homogeneity of each class and/or the accuracy of training site location and description. Where two or more training sites are available for a particular class, the mean radiances in each spectral band should be similar. If this is not the case, heterogeneity of ground cover, poor site location/interpretation or some environmental effect such as cloud, haze or shadow will result in one (or more) signatures being significantly different from the others.

Heterogeneity: where a class has been defined in specific terms (for example; immature, coniferous forest-closed canopy), the presence of deciduous trees, grasses or shrubs will result in heterogeneity. This may arise due to the difficulty of accurately identifying training sites from the 1:40,000 or 1:50,000 scale black-and-white airphotos. Heterogeneity may also arise from time-related changes that occurred between the dates of airphoto acquisition (1976, 1978 and 1980) and LANDSAT data acquisition (1980).

Site Location/Interpretation Errors: these may arise during airphoto interpretation as above, or during transfer from the airphotos to the LANDSAT imagery.

Environmental Effects: dense cloud will obliterate ground features. Haze and shadow will affect the radiation reflected from ground features altering the signature means in each spectral band. Reflectance from aerosols (e.g. smoke from forest fires) may increase the signal received by the sensor.

Table 5 lists the mean signal intensities (digital number, DN, on a scale 0-255) in each LANDSAT band for each of the training sites. Four signatures have been excluded from subsequent analysis due to inconsistency with other signatures of the same class. Consider for example the two classes H2O-DP (deep water) and BOG (bog, marsh, fen). Four training sites were established for each of these classes. For the H2O-DP class all four signatures are very similar, suggesting very homogeneous cover, not unsurprising for deep water. The BOG class however, has greater signature variation which is to be expected given the variety of species, soils and moisture levels possible in such a class. Training site 2 of this class has a significantly higher reflectance in MSS bands 4 and 5 than do the other three signatures. This may be due to heterogeneity or to poor training site location. Based on the other samples in the training set, this training site is not representative of the BOG class and it was therefore excluded from generation of the composite signature used subsequently during classification.

3.2.6 Signature Reduction

Certain pairs of classes which were separable on the airphotos by tone, texture, location and/or pattern could not be discriminated from the LANDSAT data using spectral information alone. Table 5 lists the mean intensities and the incensity range (± 1 standard deviation) for the composite signatures previously acquired. The intensity range provides some information concerning the discriminability of a pair of classes. If there is a zero, or minimal overlap between the ranges found in at least one LANDSAT band, the potential for accurate classification between two classes is high. Conversely, if for all four LANDSAT bands there is a high degree of overlap, the potential for accurate classification is very low. An analysis of Table 5 results in the following conclusions:

(i) IMFSTO (immature forest, open canopy) cannot be separated from DECID (deciduous forest) or AVLCHE (alpine shrubs).

(ii) MEADOW (riparian meadow) cannot be separated from MIXFST (mixed forest) or from ALPINE (alpine/sub-alpine grassland).

(iii) IMFSTC (immature forest, closed canopy) cannot be separated from MATURE (mature coniferous forest).

(iv) AGRIC (agriculture undifferentiated) cannot be separated from CUTREG, IMFSTO, DECID, MIXFST, ALPINE, AVLCHE, BOG or MEADOW.*

* See Table 6 for the definition of these classes.

The fact that IMFSTO cannot be separated spectrally from DECID or from AVLCHE does not by itself prevent DECID from being separated from AVLCHE. Therefore, by eliminating IMFSTO from subsequent analysis, there remains potential for discrimination between the DECID and AVLCHE classes. For the same reason the MEADOW class was eliminated from subsequent analysis.

The intensity means and ranges of IMFSTC lie totally within the intensity ranges of MATURE. The IMFSTC class cannot therefore be discriminated and has thus been excluded from the classification.

The AGRIC class shows very high predicted confusion (8 classes) because of its wide intensity range in each LANDSAT band (large SD). This is caused by the variety of crop types and crop conditions found in the training sites. This class must therefore be eliminated from subsequent analysis to prevent impact on the classification accuracies of the eight confusion classes.

3.2.7 Digital Classification

The training site signature analysis resulted in a total of sixteen classes for classification. These are listed and described in Table 6. Each pixel in the LANDSAT data-set of the study area was examined by the computer, and classified into one of the 16 classes using a Maximum Likelihood Decision Rule. Three of these classes (ROCK 1, ROCK 2 and ICE) which all relate to rock cover have been merged together into one class (ROCK, undifferentiated) for display on the output products. This was done as knowledge of different rock categories was not required for this study, and reductions in class numbers allows improved hue-contrast in the final output prints.

The distribution of the seven forestry-related classes is shown on Plate 3, the remaining classes are illustrated on Plate 4. Both of these output prints are at a nominal scale of 1:500,000. A second set of classified prints at a scale of 1:125,000 is included with this report.

3.2.8 Area Measurement

The computer classification output includes a pixel count for each class. Since each DICS pixel represents one-quarter hectare (50m x 50m) on the ground, a simple division gives the area in hectares for each class.

The entire scene shown on Plate 1 was classified. In order to acquire class area measurements for the study area alone (on Vancouver Island), a mylar sheet was overlaid on each of the 1:125,000 classification prints and polygons corresponding to each of the different classes in Johnstone Strait and the Gulf Islands were delineated. The area of each polygon was then measured using an electronic digitizing tablet exactly scaled to the print scale. Many such polygons contained more than one class. In such cases the individual class areas were calculated according to their estimated proportion in the polygon. The individual class areas in the Johnstone Strait and Gulf Islands portion of the scene were subsequently subtracted from the total scene area to give the individual and total class acreage in the study area.

Note that other digital image analysis systems may have software available which will allow for exclusion of undesired portions of a scene. Both the CCRS system in Ottawa and the GEMS system in Victoria have such software.

Table 6 lists the calculated areas of each class for both the total scene and for the study area.

4.0 CLASSIFICATION ACCURACY

4.1 Sampling Method

Sample plots with which to evaluate the accuracy of the LANDSAT classification were interpreted from the same airphotos previously used for training site acquisition (section 3.2.2). A stratified sampling technique was adopted to reduce the possibility that frequent and areal extensive classes would be oversampled, whilst small and infrequent classes would be under-represented. This can often be the case when samples are gained in a random manner, as demonstrated by Hellden (1977).

The sample size required for each class was pre-determined as a minimum of 20. Van Genderen et.al., (1978) reported that at least 20 samples per class are required for 85% interpretation accuracy, and for 90% interpretation accuracy 30 samples per class should be acquired.

The study area was geographically stratified into 47 one-hundred square kilometer (10km x 10km) quadrates. The IWIFR interpreters were asked to identify where possible one location in each quadrate for each of the 10 classes for which classification accuracy evaluation was required (Table 2) using the airphotos listed in Appendix 2.

This method resulted in a reasonable distribution of samples across the study area as illustrated in Plate 2. However, several of the small, and infrequently observed classes were under-represented, particularly the non-vegetated clearcut, deciduous forest, alpine grassland and shrub classes (Table 7). The reasons for this under-representation are discussed in section 5.1, and recommendations for improvements to the method are given in section 5.2.

One hundred and eighty-nine sample plots were identified and delineated on mylar sheets overlaid on the airphotos. Their locations were subsequently transferred to 1:50,000 NTS map-sheets, and a notation made of the interpreted land-cover. Due to changes in the classification system (sections 3.2.3 and 3.2.6) the following classes were eliminated from the accuracy evaluation: IMFSTO, IMFSTC and MEADOW. This reduced the total number of accuracy evaluation samples to 155.

The two vegetated clearcut classes (CUT.GS and CUTREG) which had previously been separately classified from the LANDSAT data were recombined into one new vegetated clearcut class (OLDCUT) to allow for comparison with the accuracy evaluation sample.

The map location of each of the 155 accuracy samples was then compared with the corresponding location on each of the 1:125,000 nominal scale LANDSAT classification maps and the interpreted ground cover was compared to the classified result. A Bausch & Lomb ZTS-Zoom Transfer Scope was used to equate the map and LANDSAT print scales. The map and prints were registered using lake and shoreline boundaries. At the scales used, the Transfer Scope is only able to register an area of approximately 150 km^2 at any one time. In the south-central part of the study area, between Stuart Lake and Bootfrog Lake to the west, and also to the east of Stuart Lake between Victoria Peak, Sutton Peak and Kokummi Mountain, suitable map-to-print registration points could not be found. Although Stewart Lake is classified on the LANDSAT image as DEEP WATER, at least two lakes are required for registration. The smaller lakes, 4 km to the north and 15 km to the east near Sutton Peak were either in shadow at the time of LANDSAT data acquisition or misclassified on the print, and as such could not be used as registration points.

The lack of suitable map-to-print registration points prevented the accurate location of 33 samples on the LANDSAT classification map. These samples were therefore not included in the accuracy evaluation, further reducing the number of samples available for this analysis to a final total of 122.

4.2 Results

The overall classification accuracy of the 11 classes for which samples were available is 68.9% (n=122). Individual classification accuracies range from 0% for rock (2 samples), to 100% for new clearcuts, alpine grasslands and deep water (Table 7). These results must be treated with caution however, as the confidence level (number of samples) for each class varies from zero confidence (n=2) to about 90% confidence (n=28).

This overall accuracy is less than would normally be expected from an analysis of LANDSAT data for land cover mapping. Schubert (1978) used a supervised approach similar to that undertaken in this investigation to classify nine Canada Land Inventory (CLI) classes at an overall accuracy of 78%, and Hellden (1980) classified seven land cover classes with relevance to land degradation and desertification studies at an overall accuracy of 73%.

One particular factor that was considered to have contributed to classification inaccuracies was the presence of haze and light clouds in the imagery. In the north-eastern and eastern parts of the study area, haze and light clouds are present (Plate 1). Additionally, in the north-western corner of the area there appears to be the residual of a jet contrail. As stated in Sectin 3.2.5, local haze or cloud conditions will affect the radiance levels of ground cover thus reducing overall classification accuracy.

This effect was examined in greater detail by repeating the classification accuracy analysis after having eliminated those samples located near to, or beneath the haze patterns. Table 8 gives the results of this exercise. The overall classification accuracy is improved to 74.3% (n=74).

5. DISCUSSION

It was not found possible to discriminate three of the desired wildlife habitat classes - IMFSTO (immature forest, open canopy), IMFSTC (immature forest, closed canopy) and MEADOW (riparian meadow) - due to their spectral similarity with other classes. These classes were therefore eliminated from the digital classification in order that they would not adversely affect the accuracy of classification of other classes (Section 3.2.6).

The overall accuracy achieved during this investigation is lower than had been anticipated, even though a thorough analysis of the spectral signatures was undertaken. Certainly part of the inaccuracy was due to local atmospheric conditions in some portions of the study area at the time of image acquisition. The effect of this is illustrated in Plate 4 where a portion of Johnstone Strait (at Yorke Island) is classified as ROCK instead of deep water due to the presence of a small wisp of cloud. When hazy and cloudy portions of the imagery were removed from the classification, overall accuracy rose from 68.9% to 74.3%.

Economic and time constraints are important factors for consideration when planning an investigation of this kind. In order to conserve both costs and time, aerial photographs were used in this project to select training sites and sample plots for the accuracy evaluation. The limitations associated with this technique are discussed in the following section, and recommendations for improvement are given in section 5.2. A more general summary discussion of the strengths and weaknesses associated with digital classification techniques is given in section 5.3. For the purpose of comparing the digital classification with the analog methods (see Section 1.0), the actual time and costs associated with this investigation are given in Section 5.4.

5.1 Limitations of the Method

5.1.1 Airphoto Interpretation

The airphotos used for training and accuracy sampling site location may have contributed to classification inaccuracies for the following reasons.

(i) Spectral content: black-and-white airphotos have limited spectral information. The IWIFR interpreters reported difficulty in distinguishing between the Bog/Fen and Riparian Meadow, Immature and Mature, and Mature and Overmature coniferous forest classes.

(ii) Scale: at the scales used, a 4 ha plot on the ground measures 1 cm^2 on a 1:20,000 scale airphoto, and 0.16 cm^2 on a 1:50,000 scale airphoto. At the latter scale in particular, reliable interpretation of small plots is very difficult and problems associated with the transfer of the plot location to the LANDSAT data-set are aggravated.

(iii) Age: full coverage of the study area is only available on the 1:50,000 scale airphotos, acquired in 1976 and 1977 (Appendix 2). Only partial coverage is available at the 1:40,000 (1980 imagery) and 1:20,000 (1978 imagery) scales. Differences in dates between airphoto and satellite data acquisition can lead to interpretation errors due to changes in land cover and land use.

It should be noted that only three of the individual spectral signatures were rejected on the basis of poor fit with other signatures of the same class (section 3.2.5). This indicates that the interpreters were able to accurately classify most classes from the airphotos. However, this also reinforces the need to examine the signature of each individual training site prior to classification as just one incorrect signature can significantly affect classification accuracy by altering the mean radiance, or increasing the standard deviation of the composite signature.

5.1.2 Atmospheric Effects

The scene selected for this investigation had local atmospheric variations which reduced overall classification accuracy (section 4.2). Such variations cannot be compensated for during digital classification and this type of analysis should therefore be restricted to cloud and haze-free scenes.

5.1.3 Classification Accuracy

The stratified approach used to gain accuracy sample plots was unsuccessful in aquiring a minimum of 20 plots for each class (section 4.1). The principal cause of this was that several classes (Deciduous, Alpine, Avalanche and Shallow Water) have a low frequency of occurrence in the study area. A second cause of class under-representation was the constraints placed upon sample selection, which included:

(i) a pattern on the airphotos must be definitively interpreted as one of the classes under investigation;

(ii) the pattern must be homogeneous;

(iii) a polygon drawn around the pattern should have an area representing not less than 5 hectares on the ground in order that minor plotting errors would not destroy the sample's usefulness;

(iv) The sample must be referenced to some feature which will allow its accurate location on the 1:50,000 scale topgraphic maps and on the 1:125,000 LANDSAT classification prints. Features used included roads, shorelines and lakes.

These constraints reduced the number of interpreted class units that could be used as accuracy sampling plots. In an attempt to gain additional samples, the particular constraints of sample area and reference features were subsequently relaxed. Plots as small as 2 ha in area were acquired, and rivers and minor streams used as reference points. Whilst the latter allowed for transfer of the sample locations to the NTS maps, such streams and rivers are not visible on the LANDSAT imagery.

Even after relaxing the above constraints we were unable to achieve an average of 20 samples per class. For the seven classes for which accuracy estimation was required (after elimination of IMFSTO, IMFSTC and

MEADOW, section 3.2.6), 110 samples were acquired (Table 7). The Deciduous (n=8) and Avalanche (n=5) classes in particular were badly under-represented and no confidence can be placed upon the accuracy results given for these two classes.

5.2 Recommendations for Improvement

5.2.1 Preliminary Analysis

An unsupervised digital classification or a visual interpetation of major strata in the data set prior to the establishment of the classification system would benefit an investigation of this nature as follows:

(i) The classification system could be designed in advance to be compatible with the remotely-sensed data;

(ii) after stratifying the scene by interpreted land cover categories, the locations of suitable training sites could be specified in advance;

(iii) sampling for accuracy estimation can be performed in each stratum allowing for full acquisition of a pre-determined number of sample sites. If a random sampling technique is adopted, over-sampling should take place in each stratum so that sample points may be selected for their ease of plotting, or ease of access if field investigations are undertaken.

5.2.2 Field Investigations

A supervised classification of LANDSAT digital data is based upon the spectral signatures acquired from co-ordinates in the data-set corresponding to the locations of the training sites. Ground knowledge of land cover patterns in the training sites at or near the time of satellite data acquisition is therefore required to ensure the correct signature, or to fully describe any variations found within a signature. It is therefore recommended that future investigations of this kind acquire training data from field investigations rather than from air photos.

Airphotos may be used to acquire data for accuracy evaluation as one or two incorrectly interpreted samples will not significantly affect the overall accuracy result. The photographs should however be of a similar age as the LANDSAT data and at scales which will allow for accurate interpetation [typically 1:20,000 for panchromatic imagery (Reeves et.al., 1975, p.1360) or 1:50,000 or smaller for colour infrared photography (Bowlby, 1981 and Reeves et al., 1975, p.1361).

5.3 Strengths and Weaknesses of Digital Classification

The principal strengths and weaknesses of digital classification are summarized below:

Spatial Resolution: Every pixel is classified during digital classification, the theoretical spatial resolution of LANDSAT DICS data thus being 0.25 hectares. However, since the DICS data are resampled raw LANDSAT data whose spatial resolution is 0.5 ha (60 x 80m), the latter figure should be considered the minimum ground resolvable area.

Output Scale: grey-scale and colour plots can be produced in real time from digital data at any desired scale if the required hardware is available. Currently only the Canada Centre for Remote Sensing has both a Versatec* grey-scale plotter and an Applicon* colour plotter available for real-time output products.

Level of Generalization: digital techniques can measure subtle differences between classes which are often not visible on analog imagery. The level of generalization in a hierarchical classification scheme can often be increased over that available by visual interpretation methods.

Precision: precision is defined as the repeatability of a value determined for each sample (Sadoway, 1980). In digital analysis, a sample is defined by the radiance as measured by the sensor in four wavelength bands (the spectral signature) and as such is a quantitative and repeatable value. Note however that the sample radiance is scene-dependent. Atmospheric, solar and sensor-related variations will alter the values obtained from the same sample location in a second LANDSAT scene.

* Trade names

Geometric Rectification: digital LANDSAT DICS data are rectified to be compatible with the Canadian 1:50,000 scale NTS maps. Raw LANDSAT digital data may also be rectified on most digital image analysis systems.

Change detection: two or more DICS scenes of the same location acquired on different dates may rapidly be digitally overlaid, and a product acquired showing only areas of change.

Data integration: topographic and other data sources in digital format may be integrated with digital LANDSAT data to improve classification accuracies or develop planning and management models.

Classification algorithms: digital classification algorithms discriminate between classes on the basis of spectral information alone. Spatial and texture pattern recognition techniques are not at present available.

Cost: digital analysis techniques are more expensive than visual interpretation methods. A LANDSAT DICS tape cost $200, and digital image analysis costs are typically $90/hour for machine time, and in excess of $50/hour for labour. Output colour prints can easily cost in excess of $100 each depending upon available facilities.

Access: access to digital image facilities is limited. There are two systems presently available in B.C., one at MacDonald, Dettwiler and Associates in Richmond, the second at the Pacific Forest Research centre in Victoria. A third system is under development at the University of British Columbia.

Time Delays: time delays are often encountered due to computer down-time, image-to-film product preparation, and even generation of the source data. Delivery time for DICS CCT's can often be as long as two months.

Atmospheric Effects: digital analysis cannot compensate for localized atmospheric effects present in a scene (section 3.2.5).

5.4 Costs

Table 9 details the budgeted and actual time and costs incurred during this investigation. There is a difference of over $4,000 between the budgeted figure and the actual cost. This difference is due primarily to an increase in the number of ground features that were originally scheduled for classification (from 8-10 classes when the budget was prepared, to 16 classes after airphoto interpretation) and the unforeseen impact that this had upon the analytical method that was adopted.

In view of the possibility of errors that might be incurred during airphoto interpretation for training site definition, the reflectance characteristics of each individual training site were examined in order that anomalous signatures within a class might be discarded. This approach does however add considerably to analysis time. Boundary delineation on the LANDSAT data-set of over 50 individual training samples took approximately 2 man-days and about 10-12 hours of computer time. Digital training for each of these training sites took another man-day, and about 4-6 hours of computer time. Subsequent analysis of the individual spectral signatures added a further man-day. These times and their cost are broken down in Table 9.

6.0 Suggestions for Further Work

The author considers that satellite data have a useful role in the provision of information for large area wildlife habitat inventories and monitoring. Four recommendations are offered for consideration if future investigations are considered:

6.1 The Role of Satellite Data for Monitoring

The repeated observations made by earth observation satellites are well suited for change detection. If a current and accurate inventory of an area is available, the satellite data in digital format can offer a rapid, timely and inexpensive update of ground conditions. Such a program would considerably reduce field-work effort. Field studies would be directed only in those areas where change is indicated.

Two digital techniques are available for the temporal comparison of two LANDSAT DICS scene. In the first technique a supervised classification is produced for each scene. The classified results are then digitally overlaid and compared to identify the areas and types of change. A simpler and more rapid method of change detection is band ratioing. In ratioing, radiances of pixels of one LANDSAT scene in one band are divided by the pixel radiances in the same band for the second scene. The data are thus compared on a pixel-by-pixel basis. Where pixel radiances are almost equal in each scene, the result of the division is approximately 1.0. In this case, the land cover is assumed to have remained constant. Where change has occurred, the result will be either less than or greater than 1.0, indicative of areas of change. Howarth and Wickware (1981) used ratios of bands 5 and 7 of two LANDSAT scenes to identify changes in vegetation and water that had occurred between 1973 and 1976 in a test area centered on Mamawi Lake, Alberta.

6.2 Interpetation of Digitally Enhanced Analog Imagery

Subtle variations within a LANDSAT image can be digitally enhanced by such methods as ratioing, contrast-stretching and principal-component analysis. Ratios of the same bands of two different scenes have been discussed in the previous section. When two different bands of the same scene are ratioed together, regions of similar spectral reflectance are clustered together regardless of brightness differences brought about by geometric factors such as surface orientation. Smith (1977) found that a visual analysis of a ratioed image provided more useful information for geologic mapping than a thematic map produced from digital classification techniques.

Contrast-stretching improves the contrast of a selected single-band image by increasing the dynamic range of brightness of features of interest in the scene to the maximum range permissible (0-255 DN). This is performed on three LANDSAT bands (normally MSS 4, 5 and 7) to produce a contrast-stretched colour composite print. Alfoldi (1980) recommended this technique for interpretation of forest features in Nova Scotia.

Principal Component enhancements are used to reduce the number of channels in a data-set (eg. LANDSAT bands) whilst retaining information content. Kourtz and Scott (1978) have successfully used this technique to reduce multi-date LANDSAT imagery to a three-channel subset for colour image production. The imagery was subsequent used by field personnel for forest fire management.

6.3 Multi-temporal Classification

Vegetation phenology affects classification accuracy. For example, it is obviously easier to discriminate between coniferous and deciduous forests during the fall or winter than during the spring or summer months. This investigation has been

based upon 4-dimensional classification (4 LANDSAT bands, one scene). Eight-dimensional (or more) classification (4 bands, summer and winter scenes) could also be undertaken with a probable significant increase in classification accuracy.

6.4 LANDSAT - D Simulation

LANDSAT-D, due to be launched in the fall of 1982, will carry a new sensor imaging in seven spectral bands, at a ground resolution of 30 meters (120 m for thermal band). Previous simulation studies have indicated that the data from this satellite will be comparable to 1:50,000 colour infrared aerial photography (Tomlins, 1981). An investigation of the potential of this satellite for wildlife habitat inventories is recommended. A digital analysis of the usefulness of each of the wavelength regions for wildlife habitat inventories should be undertaken, followed by visual interpretation of the "best" three-band colour composite.

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Table 2

ORIGINAL CLASSES FOR TRAINING SITE ACQUISITION

Classes

Class	Description	Training Site Samples Required	Class Accuracy Samples Required	Class Represented on Final Product
Clear-cut	Non-vegetated	x		x
Regenerating Clear-cut	Approx. 5-10 Yrs.	x	x	x
Open Immature	Open Canopy	x	x	x
Closed Immature	Closed Canopy	x	x	x
Mature	Approx. 40-80 Yrs.	x	x	x
Overmature	Old Growth	x	x	x
Deciduous	All Ages	x	x	x
Mixed Forest	Mixed Dec. and Con.	x	x	x
Alpine/ Subalpine	Rock, Low Veg., Shrub Grassland or Mixture	x		x
Shrub	Avalanche Areas	x	x	x
Bog/Fen		x	x	x
Riparian Meadow		x	x	x
Deep Water		x		x
Shallow Water		x		x
Rock	Undifferentiated	x		x
Agriculture	Undifferentiated	x		x
	Total	16	10	16

Table 3

EXTRA CLASSES INCORPORATED INTO THE DIGITAL TRAINING SET

Class	Description	Distinguishing Features on Enhanced False Color Infrared Image
NEWCUT	Non-vegetated clear-cut.	Blue-grey hue. High intensity. Normally linear boundaries.
CUT.GS	Vegetated clear-cut. Grass and shrub-covered.	Bright red hue. Normally linear boundaries.
CUTREG	Vegetated clear-cut. Regenerating (young conifer) cover.	Red-brown hue. Normally linear boundaries.
ROCK 1	Unvegetated rock, undifferentiated. May be partially ice or snow-covered.	Light blue-grey hue. Very high intensity. Found in mountainous regions.
ICE	Ice or snow-covered rock, undifferentiated.	White-blue hue. Very high intensity. Found on mountain peaks.
ROCK 2	Rock undifferentiated. May be sparsely vegetated.	Blue-grey hue. Medium intensity. Non-linear feature. Mostly found in hilly areas.
SHADOW	Northern slopes of mountains. Position varies with elevation.	Dark, often black hue. Non-linear. Intensity solar azimuth/angle dependent.

Original Classes	Class Expansion	Class Reduction	Final Classes: Classified	Area (ha)	Distribution on Output Prints	Accuracy Evaluation
Clear-cut, non-vegetated	same	same	x	x	x	x
Clear-cut, regenerating	clear-cut, grasses	same	x	x	x	
	clear-cut, young conifer	same	x	x	x	x
Imm. conifer, open canopy	same	excluded	-	-	-	-
Imm. conifer, closed canopy	same	excluded	-	-	-	-
Mature conifer	same	same	x	x	x	x
Overmature conifer	same	same	x	x	x	x
Deciduous forest	same	same	x	x	x	x
Mixed forest	same	same	x	x	x	x
Alpine/sub-alpine	same	same	x	x	x	x
Shrub	same	same	x	x	x	x
Bog/Fen	same	same	x	x	x	x
Riparian meadow	same	excluded	-	-	-	-
Deep Water	same	same	x	x	x	x
Shallow water	same	same	x	x	x	-
Rock, undifferentiated	rock, unvegetated	same	x	x		
	rock, ice/snow cover	same	x	x	x	x
	rock, sparsely vegetated	same	x	x		
Agriculture	same	excluded	-	-	-	-
	shadow	same	x	x	x	-
Total: 16 Original Classes	20	16	16	16	14	11

Table 4

DEVELOPMENT OF THE CLASSIFICATION SYSTEM

Table 5

SPECTRAL SIGNATURES: INDIVIDUAL AND COMPOSITE TRAINING SITES

Key: n = No. Samples; $\bar{x}$ = Mean Intensity; TS = Training Site; SD = Standard Deviation; Range = $\bar{x} \pm 1$ SD

Class		Individual Training Sites										Composite Training Sites		
		TS1		TS2		TS3		TS4		TS5				
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	Range $\bar{x} \pm 1$ SD
1. NEWCUT		n = 234		n = 178		-		-		-		n = 412		
	MSS4	28.6	2.3	29.1	3.5							28.8	2.9	25.9- 31.7
	MSS5	38.4	3.5	37.0	4.1							37.8	3.9	33.9- 41.7
	MSS6	51.2	4.8	50.7	4.6							51.0	4.7	46.3- 55.7
	MSS7	49.9	5.5	49.9	5.8							49.9	5.6	44.3- 55.5
2. CUT.GS		n = 51		n = 90		n = 56		-		-		n = 197		
	MSS4	34.1	3.6	31.5	2.5	40.9	4.0					34.8	5.1	29.7- 39.9
	MSS5	41.9	4.9	38.7	2.9	53.7	7.2					43.8	8.1	35.7- 51.9
	MSS6	83.7	7.3	68.7	6.1	72.3	7.6					73.6	9.2	64.4- 82.8
	MSS7	85.5	8.8	73.0	6.7	68.9	7.7					75.1	9.9	65.2- 85.0
3. CUTREG		n = 135		n = 95		n = 139		-		-		n = 369		
	MSS4	27.3	2.0	24.0	1.4	24.2	2.5					25.3	2.6	22.7- 27.9
	MSS5	31.9	2.8	26.3	2.0	26.7	3.5					28.5	3.9	24.6- 32.4
	MSS6	62.5	5.9	72.7	4.6	59.8	7.3					64.0	8.0	56.0- 72.0
	MSS7	66.1	5.9	78.5	5.4	61.1	7.4					67.4	9.4	58.0- 76.8
4. IMFSTO		n = 32		n = 33		n = 17[1]		-		-		n = 65		
	MSS4	21.1	2.4	20.3	1.3	17.4	0.8					20.7	2.0	18.7- 22.7
	MSS5	17.8	2.7	17.5	1.6	13.1	1.0					17.6	2.2	15.4- 19.8
	MSS6	78.5	6.9	85.4	7.0	38.9	3.3					82.0	7.8	74.2- 89.8
	MSS7	90.8	8.2	97.5	8.9	39.6	4.9					94.2	9.2	85.0-103.4

Table 5 (continued)

Class		Individual Training Sites										Composite Training Sites		
		TS1		TS2		TS3		TS4		TS5				
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	Range $\bar{x} \pm 1$ SD
5. IMFSTC		n = 41		n = 80		n = 85		-		-		n = 206		
	MSS4	19.6	1.4	18.8	1.0	18.9	1.3					19.0	1.2	17.8- 20.2
	MSS5	16.1	1.9	13.9	1.2	15.0	1.8					14.8	1.8	13.0- 16.6
	MSS6	60.8	4.1	56.1	3.2	52.0	4.0					55.3	5.0	50.3- 60.3
	MSS7	62.4	4.7	61.2	3.2	57.4	4.3					59.9	4.5	55.4- 64.4
6. MATURE		n = 41		n = 33		-		-		-		n = 74		
	MSS4	19.0	1.5	18.4	1.5							18.8	1.5	17.3- 20.3
	MSS5	14.6	1.9	14.2	1.7							14.4	1.9	12.5- 16.3
	MSS6	65.3	7.0	46.7	5.0							57.0	11.1	45.9- 68.1
	MSS7	75.9	7.3	47.4	5.3							63.2	15.6	47.6- 78.8
7. OLDFST		n = 41[2]		n = 138		n = 12[2]		n = 281				n = 419		
	MSS4	18.9	1.7	15.6	1.2	16.2	1.2	17.0	1.4	-		16.6	1.5	15.1- 18.1
	MSS5	15.9	1.7	11.0	1.6	12.8	1.7	13.5	1.6			12.7	2.0	10.7- 14.7
	MSS6	43.0	5.8	27.8	4.7	50.2	4.8	31.1	3.7			30.0	4.3	25.7- 34.3
	MSS7	44.0	6.8	27.8	6.0	55.9	6.3	29.7	4.1			29.1	4.9	24.2- 34.0
8. DECID		n = 11		n = 42		n = 28		-		-		n = 81		
	MSS4	22.2	1.5	21.7	1.7	22.7	1.4					22.1	1.6	20.5- 23.7
	MSS5	19.9	1.9	19.1	1.6	20.1	1.4					19.6	1.7	17.9- 21.3
	MSS6	100.4	7.0	89.9	5.6	80.5	4.8					88.1	8.6	79.5- 96.7
	MSS7	115.0	6.6	103.5	6.3	94.3	6.2					101.9	9.2	92.7-111.1
9. MIXFST		n = 154		n = 151		-		-		-		n = 305		
	MSS4	20.1	1.5	23.1	2.2							21.6	2.4	19.2- 24.0
	MSS5	17.0	1.9	21.5	2.4							19.2	3.1	16.1- 22.3
	MSS6	75.3	8.3	52.6	5.2							64.1	13.3	50.8- 77.4
	MSS7	88.0	9.9	57.1	5.3							72.7	17.4	55.3- 90.1

Table 5 (continued)

Class	Individual Training Sites										Composite Training Sites		
	TS1		TS2		TS3		TS4		TS5				
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	Range $\bar{x} \pm 1$ SD
10. ALPINE	n = 41		n = 191		n = 5		n = 10		n = 19		n = 266		
MSS4	24.1	3.3	22.8	2.5	25.4	0.8	20.5	1.4	22.6	1.8	23.0	2.6	20.4- 25.6
MSS5	27.0	5.3	24.0	3.8	26.4	0.5	21.8	1.2	22.4	1.7	24.3	4.1	20.2- 28.4
MSS6	55.6	10.2	60.9	5.5	68.0	1.1	58.5	7.8	71.9	6.2	60.9	7.6	53.3- 68.5
MSS7	58.6	10.9	65.9	6.5	74.2	4.5	63.6	7.1	77.8	5.3	65.7	8.5	57.2- 74.2
11. AVLCHE	n = 14		n = 8		-		-		-		n = 22		
MSS4	19.6	1.6	21.9	2.1							20.5	2.1	18.4- 22.6
MSS5	16.6	2.4	19.4	2.9							17.6	2.9	14.7- 20.5
MSS6	76.0	7.9	86.0	15.0							79.6	12.0	67.6- 91.6
MSS7	93.3	11.1	107.5	17.6							98.5	15.4	83.1-113.9
12. BOG	n = 11		n = 18[2]		n = 19		n = 13		-		n = 43		
MSS4	21.2	1.0	23.6	1.6	21.6	1.3	21.6	1.5			21.5	1.1	20.2- 22.8
MSS5	20.6	1.9	26.2	2.7	18.3	1.3	20.4	0.6			19.5	1.7	17.8- 21.2
MSS6	69.1	5.2	68.8	7.8	75.6	4.6	73.4	4.3			73.3	5.4	67.9- 78.7
MSS7	82.1	9.0	80.3	8.4	87.4	3.7	85.3	5.3			85.4	6.3	79.1- 91.7
13. MEADOW	n = 39		n = 5		-		-		-		n = 44		
MSS4	21.7	1.7	20.8	1.3							21.6	1.7	19.9- 23.3
MSS5	22.3	2.4	20.0	2.2							22.0	2.5	19.5- 24.5
MSS6	66.9	7.7	54.0	8.4							65.4	8.8	56.6- 74.2
MSS7	75.1	9.4	63.6	7.8							73.8	10.0	63.8- 83.8
14. H2O-OP	n = 55		n = 1322		n = 1543		n = 146		-		n = 3066		
MSS4	13.5	1.0	14.5	1.1	14.5	1.1	13.4	1.1			14.4	1.1	13.3- 15.5
MSS5	7.5	1.1	7.5	1.1	7.5	1.1	7.5	1.3			7.5	1.1	6.5- 8.6
MSS6	3.0	2.0	2.6	1.1	2.6	1.1	3.0	1.5			2.6	1.1	1.5- 3.7
MSS7	0.8	1.0	0.1	0.3	0.1	0.3	0.3	.8			0.1	0.4	0.0- 0.5

Table 5 (continued)

Class		Individual Training Sites										Composite Training Sites		
		TS1		TS2		TS3		TS4		TS5				
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	Range $\bar{x} \pm 1$ SD
15. H2O-SH		n = 33		n = 55		-		-		-		n = 88		
	MSS4	22.6	1.3	28.6	1.6							26.4	3.2	23.2- 29.6
	MSS5	27.3	3.0	28.6	1.9							28.1	2.4	25.7- 30.5
	MSS6	29.5	7.1	36.0	4.0							33.6	6.2	27.4- 39.8
	MSS7	18.8	8.2	27.0	5.6							23.9	7.8	16.1- 31.7
16. ROCK 1		n = 77		-		-		-		-		n = 77		
	MSS4	128.4	27.5									128.4	27.5	100.9-155.9
	MSS5	145.0	33.0									145.0	33.0	112.0-178.0
	MSS6	121.9	29.6									121.9	29.6	92.3-151.5
	MSS7	64.8	19.1									64.8	19.1	45.7- 83.9
17. ICE		n = 15		-		-		-		-		n = 15		
	MSS4	183.8	19.8									183.8	19.8	164.0-203.6
	MSS5	217.7	26.8									217.7	26.8	190.9-244.5
	MSS6	195.4	25.3									195.4	25.3	170.1-220.7
	MSS7	116.1	15.1									116.1	15.1	101.0-131.2
18. ROCK 2		n = 121		-		-		-		-		n = 121		
	MSS4	37.9	10.8									37.9	10.8	27.1- 48.7
	MSS5	47.3	11.5									47.3	11.5	35.8- 58.8
	MSS6	58.2	10.4									58.2	10.4	47.8- 68.8
	MSS7	49.1	9.5									49.1	9.5	39.6- 58.6
19. AGRIC		n = 87		n = 26		-		-		-		n = 113		
	MSS4	21.9	3.2	25.2	1.9							22.7	3.2	19.5- 25.9
	MSS5	19.9	4.1	21.7	1.9							20.3	3.8	16.5- 24.1
	MSS6	68.1	9.8	94.2	8.9							74.1	14.6	59.5- 88.7
	MSS7	75.7	9.4	106.1	9.3							82.7	15.9	66.8- 98.6
20. SHADOW		n = 1053		n = 220		-		-		-		n = 1273		
	MSS4	12.2	1.6	12.4	1.5							12.2	1.6	10.6- 13.8
	MSS5	6.9	1.6	6.5	1.4							6.8	1.6	5.2- 8.4
	MSS6	8.0	5.0	7.0	3.7							7.8	4.8	3.0- 12.6
	MSS7	4.7	5.5	3.3	3.8							4.5	5.2	0.0- 9.7

1 This training site was situated in a shadowed portion of the image and was thus not included in the composite signature.
2 Inconsistency with other signatures in the class led to the decision to eliminate these training sites from the composite signature.

Class	Description	Output Product (Plate)	Code (Color)	Area in Hectares	
				Full Scene	Study Area
1. NEWCUT	Non-vegetated Clearcut	3	Red	4,462	3,447
2. CUT.GS	Vegetated Clearcut, Grass and Shrub Cover	3	Purplish Red	13,808	12,581
3. CUTREG	Vegetated Clearcut, Regeneration (young conifer) Dominant	3	Purplish Blue	26,678	25,505
4. DECID	Deciduous Forest	3	White	9,065	7,590
5. MIXED	Mixed Deciduous/Coniferous Forest	3	Yellow	50,725	41,042
6. MATURE	Coniferous Forest (includes immature)	3	Green	112,441	100,485
7. OLDFST	Overmature Coniferous Forest	3	Light Blue	90,366	85,148
8. BOG	Bog and Fen		Red	12,071	9,462
9. H2O-SH	Shallow Water	4	Purplish Red	6,341	4,391
10. H2O-DP	Deep Water	4	Purplish Blue	23,296	5,314
11. ALPINE	Alpine/Subalpine Grassland, Rock and Shrub	4	White	28,744	27,006
12. SHADOW	Shadowed Portions of Scene	4	Yellow	23,531	21,227
13. AVLCHE	Avalanche Areas, Shrub Dominant	4	Green	2,771	2,648
14. ROCK 1	Undifferentiated Non-vegetated Rock			8,949	
15. ROCK 2	Undifferentiated Rock. May be sparsely vegetated	4	Light Blue	3,945	2,249
16. ICE	Undifferentiated Rock. Ice or Snow-covered			47	
			Total	417,240	348,095

Table 6. FINAL CLASSIFICATION SYSTEM and AREA MEASUREMENT

LANDSAT CLASSIFICATION

Air Photo Interpretation		(n)	A	B	C	D	E	F	G	H	J	K	L
A	NEWCUT	(2)	1.0	-	-	-	-	-	-	-	-	-	-
B	OLD CUT	(28)	-	.68	.04	.14	-	.14	-	-	-	-	-
C	MATURE	(14)	-	-	.64	-	-	.36	-	-	-	-	-
D	OLDFST	(27)	.07	-	.11	.71	-	.11	-	-	-	-	-
E	DECID	(8)	-	-	.25	.25	.12	.38	-	-	-	-	-
F	MIXED	(11)	.09	-	.09	-	.09	.73	-	-	-	-	-
G	ALPINE	(4)	-	-	-	-	-	-	1.0	-	-	-	-
H	AVLCHE	(5)	-	-	-	-	-	-	.40	.40	-	-	.20
J	BOG	(17)	-	-	-	-	-	.06	-	-	.94	-	-
K	H2O-DP	(4)	-	-	-	-	-	-	-	-	-	1.0	-
L	ROCK	(2)	-	-	-	-	-	-	-	1.0	-	-	0.0

Overall Classification Accuracy = 68.9% (n = 122)

Table 7

CLASSIFICATION ACCURACY AND CONFUSION MATRIX

(A) Total Study Area

LANDSAT CLASSIFICATION

Air Photo Interpretarion			(n)	A	B	C	D	E	F	G	H	J	K	L
	A	NEWCUT	(1)	1.0	-	-	-	-	-	-	-	-	-	-
	B	OLD CUT	(19)	-	.58	.10	.22	-	.10	-	-	-	-	-
	C	MATURE	(3)	-	-	1.0	-	-	-	-	-	-	-	-
	D	OLDFST	(21)	.10	-	.10	.76	-	.04	-	-	-	-	-
	E	DECID	(3)	-	-	-	-	.33	.66	-	-	-	-	-
	F	MIXED	(4)	-	-	.25	-	-	.75	-	-	-	-	-
	G	ALPINE	(4)	-	-	-	-	-	-	1.0	-	-	-	-
	H	AVLCHE	(2)	-	-	-	-	-	-	-	0.5	-	.50	-
	J	BOG	(11)	-	-	-	-	-	-	-	-	1.0	-	-
	K	H2O-DP	(4)	-	-	-	-	-	-	-	-	-	1.0	-
	L	ROCK	(2)	-	-	-	-	-	-	-	1.0	-	-	0.0

Overall Classification Accuracy = 74.3% (n = 74)

Table 8

CLASSIFICATION ACCURACY AND CONFUSION MATRIX

(B) Haze-Free Portion of Study Area

Table 9

COMPARISON OF BUDGETED AND ESTIMATED REAL COSTS*

Task	Budgeted Cost	Estimated Real Cost*
1. General Project Management	not budgeted for	1 day @ $400
2. Analysis - interpretation of training sites and accuracy evaluation samples	3 days @ $300	BCR staff: 4 days @ $300 MOF/MOE staff:ca. 12 man days
- classification	2 days @ $400	- delineation of training sites 2 days @ $400 - acquisition of spectral reflection data: 1 day @ $400 - analysis of spectral reflectance data: 1 day @ $400 - classification: 1 day @ $400
- computer time	10 hrs. @ $ 90	24 hrs @ $ 90
3. Accuracy Evaluation	3 days @ $400	4 days @ $300
4. Report Writing	3 days @ $400	5 days @ $400
5. Report Production	$385	$385
6. Materials	$220	$600
7. Travel Expenses	$250	$300
Total	$5,855 + 10% Contingency	$10,245

* Actual Costs were approximately $11,500. The difference ($1000) is due to familiarization with the Image Analysis System.

Appendix 1

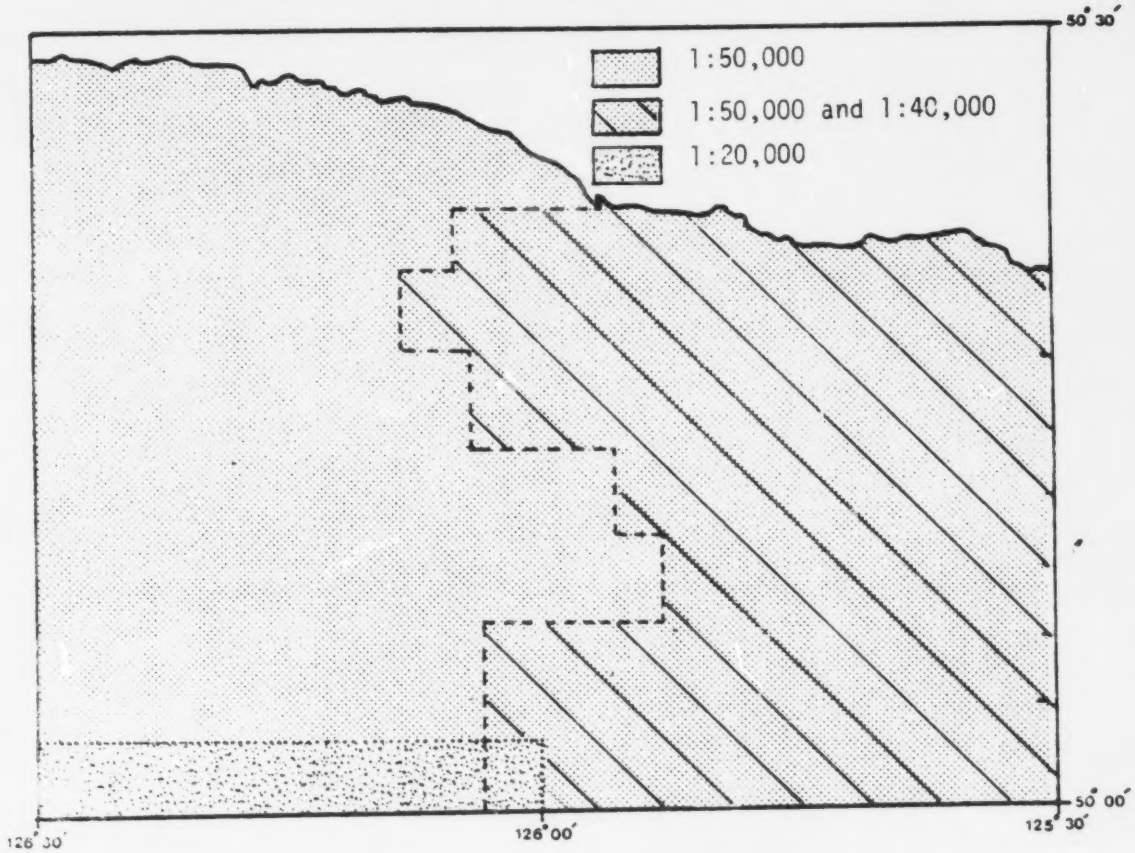
CONTACT NAMES

AIR PHOTO ANALYSIS AND TRAINING SITE ACQUISITION

Dr. G. Tomlins	B.C. Research
Mr. S. Parmar	B.C. Research
Mr. R. Davies	Ministry of Environment
Mr. D. Janz	Ministry of Environment
Mr. J. Youds	Ministry of Environment
Mr. K. Brunt	Ministry of Environment
Mr. L. Peterson	Ministry of Environment

Appendix 2

PROVINCIAL GOVERNMENT AIR PHOTOS USED IN THE INVESTIGATION



Air Photo Coverage: Sayward Forest Study Area

Flight line	Date of Imagery	Nominal Scale
BC 5749	September 20, 1976	1:50,000
BC 5752	September 20, 1976	1:50,000
BC 7714	September 10-12, 1977	1:50,000
BC 78075	June 28, 1978	1:20,000
BC 78080	June 28, 1978	1:20,000
BC 80048	June 18, 19, 1980	1:40,000

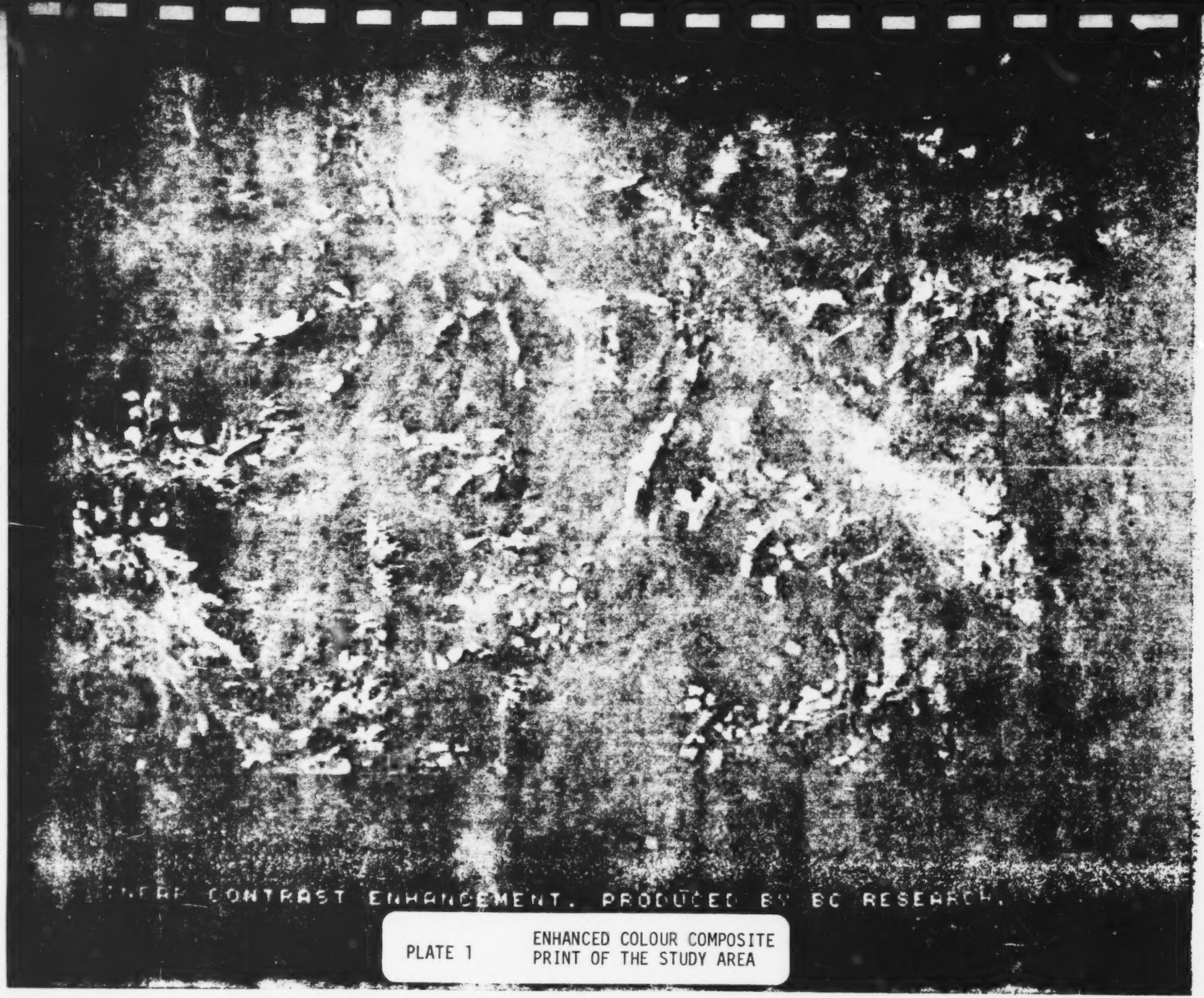


PLATE 1 ENHANCED COLOUR COMPOSITE PRINT OF THE STUDY AREA

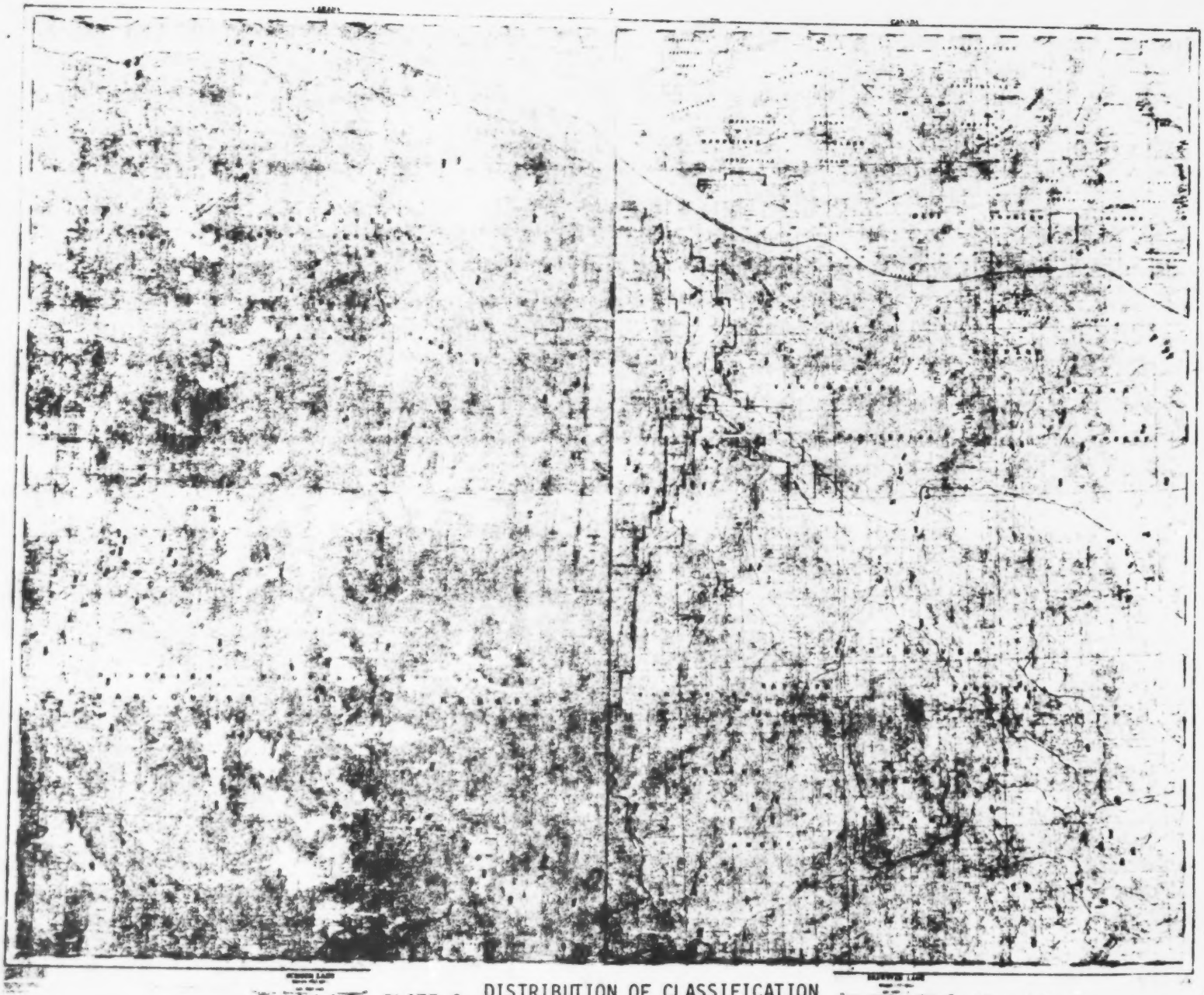


PLATE 2 DISTRIBUTION OF CLASSIFICATION ACCURACY SAMPLE SITES

PLATE 3. CLASSIFICATION RESULT A: FORESTRY-RELATED CLASSES

Key: Scale: 1:500,000

RED: unvegetated clearcut

PURPLISH RED: vegetated clearcut (grass and shrubs)

PURPLISH BLUE: vegetated clearcut (young conifers)

WHITE: deciduous forest

YELLOW: mixed forest

GREEN: mature coniferous forest

LIGHT BLUE: overmature coniferous forest

BROWN: unclassified (see Plate 4)

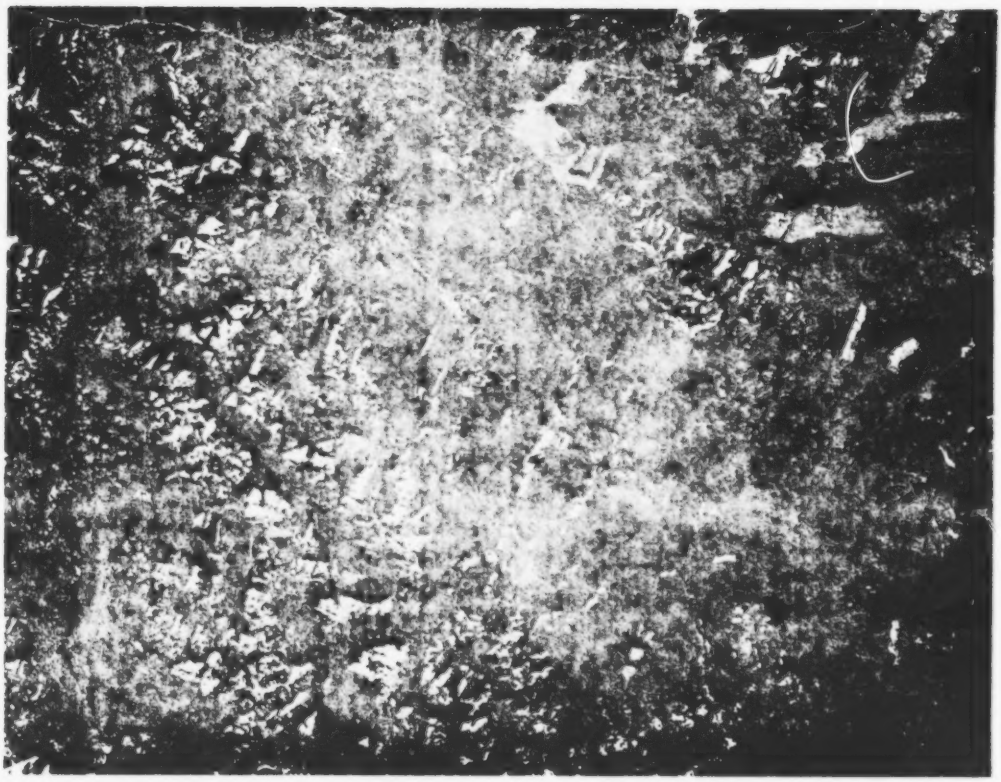


PLATE 4. CLASSIFICATION RESULT B: NON-FOREST CLASSES

Key: Scale: 1:500,000

RED: bog, marsh, fen

PURPLISH RED: shallow water

PURPLISH BLUE: deep water

WHITE: alpine/sub-alpine grasslands

YELLOW: shadow

GREEN: alpine shrubs/ avalanche zones

LIGHT BLUE: rock undifferentiated

BROWN: unclassified (see Plate 3)

APPENDIX D

SAMPLE OF FIELD DATA RECORDING FORM

TALISMAN Land Resource Consultants Project No. 81-068

LANDSAT WILDLIFE HABITAT
MAP EVALUATION

Date: _____

Surveyors: _____

_____

Transect Ident.

Sample Point Ident.	Veg. Resource Description	Sight Direct. (Range)	Score		
			KW	JB	GT

APPENDIX E

SAMPLE OF USER SURVEY QUESTIONNAIRE

TALISMAN Land Resource Consultants

QUESTIONNAIRE

To Evaluate Wildlife Habitat Maps Produced by
Three Classification Methods of Landsat Imagery

1. Comment on the legend of each map. Are the map types meaningful for wildlife/forestry research? (please use back of page if required)

_____

_____

_____

_____

_____

_____

2. Each author has selected a different classification method (1) Watson (CAV) uses numbers to represent wildlife habitat types on the map. While (2) Bunning (Visual) has selected letter symbols and (3) Tomlin (Thematic) uses colour. Do you have any preference? Why? (Please list in order, and use back of page if required)

1. _____

2. _____

3. _____

3. Which map best indicates the spatial relationships (size, pattern distribution and type) of wildlife habitats in the study area? Why? How would you rate the other two maps?

_____

_____

_____

_____

_____

_____

_____

4. Is the information presented on each map appropriate for the scale? Please comment for each map.

5. Which map would be best for locating study areas and study plots? Which would be the worst? Why?

6. Do you think that wildlife habitat mapping using Landsat imagery as a base should be extended to other areas of Vancouver Island, or elsewhere in the Province? Which method? Why?

7. Please rate each map on a scale of 1 to 5 for the following criteria. (very poor = 1, poor = 2, acceptable = 3, good = 4, very good = 5).

CRITERIA	WATSON (CAV)	BUNNING (VISUAL)	TOMLIN (THEMATIC)
A. General Readability			
B. Utility for Wildlife Forestry Research			
C. Choice of Map Types (Legend)			
D. Ease of Handling			
E. Accuracy			
F. Clarity			
G. Ability to Make Changes to Map			
H. Use of Map in Field			
I. Use of Map in Office			
J. Reproducibility			
K. Compatibility with your other map bases			

8. Do any of the three mapping methods have special research applications to your particular study?

   A. Why _____

   _____

   B. Rate other two methods _____

   _____

9. Do any of the three mapping methods have special management applicatons?

   A. Why _____

   _____

   _____

   B. Rate other two methods _____

   _____

   _____

10. Any additional comments?

_____

_____

_____

_____

_____

_____

_____

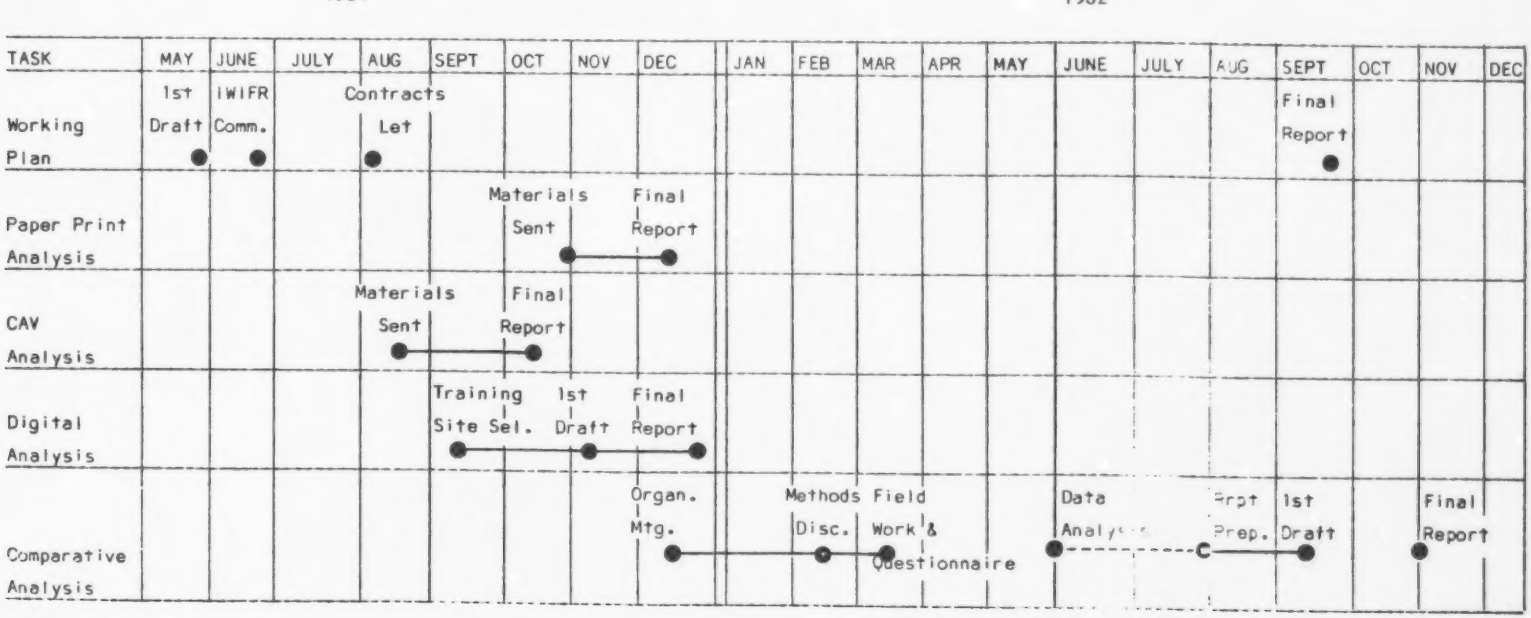
_____

APPENDIX F

SUMMARY OF TIME REQUIREMENTS TO COMPLETE STUDY

APPENDIX F

SUMMARY OF TIME REQUIREMENTS TO COMPLETE STUDY



APPENDIX G

REVISIONS TO WORKING PLAN

LANDSAT CLASSIFICATION: EVALUATION OF IMAGE ANALYSIS METHODOLOGIES FOR WILDLIFE HABITAT MANAGEMENT AND RESEARCH PLANNING

(Sadoway, 1980b)

STUDY AREA

The area choosen for this study is located on northeastern Vancouver Island and encompasses a major portion of the Sayward Provincial Forest. The study area is identified by the NTS quadrants 92K 4, 5 and 92L 1, 8.

MATERIALS

All Landsat formats were provided to the analysts. At the time of ordering, all format prices had increased. New prices are:

paper print	$ 90.00
positive transparancies	12.80
DICS tapes	200.00

It was found that the delineating of wildlife habitat types was very difficult on the paper print of the scale 1:250 000. Consequently, a 1:125 000 Landsat paper print of the study area was obtained for the analysis.

Revision of the study area from NTS grids 92K 3, 4, 5, 6 to 92K 4, 5 and 92 1, 8 necessitated ordering two DICS tapes. The revised area is longitudinally bisected by a zone boundary and data could not be geometrically produced onto one tape without distortion occuring.

Material specifications are presented in Table 1.

TABLE 1. LANDSAT IMAGE AND AERIAL PHOTOGRAPH SPECIFICATIONS

	LANDSAT IMAGES			
FORMAT	PRINT	TRANSPARENCIES	DICS	AERIAL PHOTOS
TYPE	Color	Black and White	DICS	Black and White
SIZE	742 mm	185 mm	2x2 NTS Quadrants	
SCALE	1:250,000[a] 1:125,000[b]	1:1,000,000	N/A	1:20,000 1:40,000 1:50,000
NO.	2	4[c]	2	101 ordered balanced burrowed
COST (per)	$90	12.80	200	N/A
SUPPLIED BY	Prince Albert Satellite Stn. Prince Albert, Saskatchewan		Canada Centre for Remote sensing, Ottawa, Ont.	Surveys and Mapping, MOE, Victoria

[a] print originally ordered
[b] enlargement of study area
[c] one of each band

ANALYSIS RESPONSIBILITIES

Contracts were awarded to:

John Bunning, Talisman Land Resource Consultants, Vancouver for Paper Print Analysis

Kent Watson, International Range Remote Sensing Ltd., Kamloops for Positive Transparencies - CAV Analysis

Geoff Tomlins, B.C. Research, Vancouver for Digital Analysis for DICS Tapes

Wayne Biggs and Jace Standish, Talisman Land Resource Consultants for the Comparative Evaluation

COSTS

After reviewing the working plan (Sadoway 1980) each analyst submitted a revised listing of their costs of analysis. These changes are as follows:

INDIVIDUAL ANALYSIS COSTS

Method: Visual Analysis using Paper Print

Analyst: John Bunning, Talisman Land Resource Consultants

Analysis		
	5 days @ $225/day	$1125
Report		
	5 days @ $225/day	1125
	TOTAL	$2250

Methods: Visual Analysis using Positive Transparencies and CAV

Analyst: Kent Watson, International Range Remote Sensing Ltd.

Analysis	
10 days @ $250/day	$2500
Report	
2 days @ $250/day	500
Travel Expenses (to Edmonton from Kamloops)	
Car 1000 miles @ 294/mile	290
Room and Board	
Room 3 nights @ $50/night	150
Board	125
	3565
10% contingency	360
	$3925

Method: Digital Analysis using DICS tape

Analyst: Geoff Tomlins, B.C. Research, Vancouver

Analysis	
Training Site Determination 3 days @ $300/day	$ 900
Classification	
labour - 2 days @ $400	800
computer time 10hr. @ $90/hr MDA, Van.	900
Accuracy Evaluation 3 days @ $400/day	1200
Report	
3 days @ $400/day	1200
Typing	85
Production	300

Materials

Film	20
Paper Prints	200

Travel

Flight, Roundtrip Vancouver to Victoria	100
Room and Board	150
	5855
10% contingency	585
	$6440

Method: Comparative Evaluation

Anaysts: Wayne Biggs and Jace Standish, Talisman Land Resource Consultants

Analysis

Organization and Evaluation 5 days @ $365/day	$1875
Field Work 10 days @ $375	3750
Data Analysis 10 days @ $375	3750

Report

10 days @ $375	3750
Expenses	2400
	$15525

TOTAL COSTS

Materials

Landsat Images

Paper Prints 2 @ $90 each	$ 180
Positive Transparencies 4@ $12.50 each	51.20
DICS Tapes (2)	310
Handling charges	15
Aerial Photographs	/
Topographic Maps (1:250,000)	/

Analysis

Visual Methods	
Paper Print	2250
Positive Transparencies/CAV	3925
Digital Method	
DICS Tape	6440
Comparative Evaluation	15525
	$28681.20